ON THE SPECTRA OF ARGON.

By H. KAYSER.

During the preceding summer I published a part of the blue spectrum of argon,[1] in the expectation that the red spectrum, as well as the rest of the blue spectrum, would shortly follow. It was unfortunately impossible to carry out my plan, for several reasons, the principal of which was the unsuitability of the conditions at the Physical Institute at Bonn. The building is situated at the corner of two of the busiest streets in the city, and the traffic gives rise to such vibrations within the rooms that it is impossible to carry on any investigations with apparatus requiring perfect stability of adjustment.

In parts of the spectrum for which an exposure of half an hour was sufficient, I succeeded in making fairly good progress, although many of the plates were poor; but when exposures of from two to three hours became necessary, the probability that the grating would remain so long undisturbed by tremors, and consequently give sharp spectra, became much less. In fact, I often exposed twelve or more plates before a serviceable negative was obtained. Frequently I was on the point of giving up the work altogether, as impossible of execution at Bonn, when

[1] *Chem. News,* 72.

a successful plate would encourage me to continue. In the parts of the spectrum with shortest wave-lengths, *i.e.*, above λ 3000, and in the red, yellow and green, an exposure of even three hours is not sufficient to obtain all the lines. With exposures of from four to eight hours I have indeed obtained negatives of the spectrum, but they were all so blurred that measurement of the spectral lines was quite out of the question.

Thus I was finally compelled to abandon the complete investigation of the argon spectrum, and I here give the results for
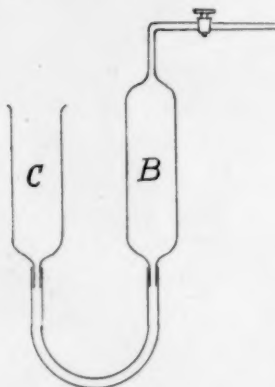

Fig. 1

such parts of the spectrum as I was able to obtain under the unfortunate circumstances already alluded to.

The argon was obtained from air in the known manner, by causing the air, after it had been freed from CO_2, H_2O and O, to pass several times over glowing magnesium. The resulting gas contained about 60 per cent. of argon, and I am greatly indebted to Dr. Bettendorff for twice preparing a considerable quantity of it in this purified condition. It was introduced into a vessel, the form of which is shown in the accompanying figure. *B* contains about 400 cubic centimeters; on its upper side it has a capillary tube, bent at a right angle, and provided with a stopcock. Two electrodes are sealed into the glass, leaving a striking distance between them of from six to eight millimeters. The tube is graduated. On the lower side it is connected with the

open vessel *C* by means of rubber tubing. Both vessels having been filled with caustic potash, impure A and then an equal volume of O are admitted by the cock, and then the spark from an induction coil is passed through the mixture of gases. NO_2 is formed, and absorbed by the caustic potash. At first the volume diminishes very rapidly, then more slowly, and finally no more change occurs. I have always allowed sparks to pass until no further contraction was perceptible in the last twenty-four hours. The O was obtained electrolytically from water acidulated with phosphoric acid, and at the end of the operation it was always my custom to admit 20^{cc} to 30^{cc} of electrolytic hydrogen and produce an explosion, in order to convert any carbon compounds that might be present into CO_2, and thus to eliminate them.

The vessel *C* was then lowered and freed from caustic potash, while *B* was slightly warmed, and thereby some additional fluid was driven out. A small quantity of a solution of pyrogallic acid was placed in *C*, and drawn over into *B* by warming the latter, in order to absorb the superfluous oxygen. After twenty-four hours the capillary tube was connected with the mercury air pump, in connection with which was also a vessel *D* containing phosphoric anhydride. This vessel was exhausted, while the glass was strongly heated, to about $0^{mm}.001$, and finally, by opening the cock, the argon was transferred from the vessel *B* to *D*, from which it was drawn whenever required for filling Geissler tubes.

In spite of all these precautions I have not always succeeded in obtaining argon perfectly pure. Traces of N and C were often present, although, at the low pressure which is most favorable to the production of the argon spectrum, they were not troublesome. Traces of the bands of cyanogen and nitrogen also frequently appeared in the ultra-violet.

Two forms of Geissler tubes were used. For the visible spectrum the form was the usual one of a capillary tube joining two larger tubes in which were sealed aluminium electrodes. For the shorter wave-lengths, which are strongly absorbed by glass, I used a form which is essentially that of V. Schumann,

to whom I am indebted for information regarding the details.
The figure gives a view of the front part of the tube in natural
size.   *A* is a quartz stopper, with plane and parallel ends which
are perpendicular to the optical axis.   Its conical surface is
unpolished, and is ground to accurately fit the neck of the tube.
Before the stopper is inserted, a very little grease is rubbed on
its outer end, and during the pumping the external pressure
drives the grease somewhat further inward, but the inner half of
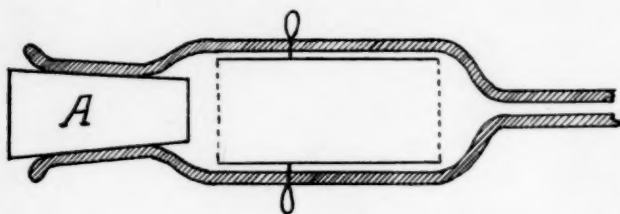the stopper remains dry, and no vapor from the grease enters

FIG. 2

the tube.   The electrode has the form used by Ames—that
of a cylindrical roll of aluminium foil, the view being unob-
structed along the axis.   The other half of the tube has a simi-
lar electrode, and is provided with a small lateral tube for admit-
ting the gas.

Great difficulties are encountered in working with argon
tubes, since after some use the gaseous contents invariably disap-
pear, particularly when the red spectrum is produced.   It is well
known that when electrodes are made of platinum, the metal is
disintegrated, and is deposited in the form of a mirror on the
inner surface of the tube, while with aluminium this unpleasant
action does not generally occur.   But in argon aluminium also
is attacked.   As soon as the action takes place, the gaseous
contents begin to disappear, the glass begins to fluoresce, and
finally the discharge will no longer pass.   If the electrodes are
thin ($0^{mm}.5$), this final result is seldom reached, since before it
can happen the electrodes become white hot, melt, and the tube
breaks.   In later experiments I therefore had the electrodes
made with a thickness of from two to three millimeters, and I

have thought that with the smaller heating effect the disintegration of the surface of the electrode and the rate of disappearance of the gas have also been diminished. The action nevertheless occurs, even with the large cylindrical electrodes. What becomes of the vanished argon—whether it forms a combination with the dispersed aluminium or is merely absorbed by it—I have not been able to ascertain; it is at any rate not liberated again by heating the aluminium deposit. Neither have I been able to determine the conditions on which depend the very different lasting qualities of the argon tubes. Many of the tubes become unserviceable after only two or three hours' use; others last as long as forty or fifty hours. These circumstances materially increase the difficulty of the investigation. Altogether I have had to fill as many as fifty different tubes.

It was shown by Crookes that the red spectrum of argon is produced when the ordinary discharge is sent through the tube, and the blue spectrum when a condenser is connected with the induction coil and the spark made to traverse a break in the circuit. In general this statement is correct when the pressure is about two millimeters, which is the pressure most favorable to the production of the red spectrum; but at a smaller pressure the blue spectrum can be obtained without a Leyden jar and interruption in the circuit, and with them, at a higher pressure, the red. In general, therefore, both spectra are seen together, even at the favorable pressure of two millimeters, unless the intensity of the discharge is properly regulated. It is much easier to obtain the blue spectrum pure, *i. e.*, free from lines of the red spectrum, than the reverse condition; for the red spectrum the current must be more exactly regulated to suit the pressure of the gas, but by doing this it is possible to obtain the red spectrum quite pure, and most of my plates show no trace of even the strongest lines of the blue spectrum.

The discharge was furnished by an induction coil capable of giving a fifteen-centimeter spark, the primary current of from eight to twelve ampères being derived from four to eight storage batteries arranged in series.

The spectra were obtained with the aid of a concave grating of the largest kind, belonging to the Berlin Academy of Sciences. Its aperture is six inches and its radius of curvature 6.5 meters. The tubes were placed close to the slit-plate, with the capillary bore parallel to the slit, except in the case of the quartz-stoppered tubes, which were of course so placed that the capillary bore was perpendicular to the slit-plate. In order to give the means of determining wave-lengths, iron electrodes were also placed diagonally in front of the slit, the spark between them being produced by a second induction coil. Both sources of light were kept in action during the whole time of exposure, and I believed that a relative displacement of the iron and argon spectra was in this way made quite impossible. Unfortunately this assumption turned out to be erroneous. Different plates showed that the argon lines were displaced with reference to the iron lines, sometimes toward the red and sometimes toward the violet, the displacement sometimes amounting to as much as 0.2 Ångström units.

This circumstance I explained in the following manner : Let us suppose that the two sources of light in front of the slit are not quite correctly adjusted, but are so placed that the first illuminates only one-half of the grating and the second the other half. If both sources emitted the same wave-lengths, the images formed by the two halves of the grating would nevertheless exactly coincide, provided the photographic plate were exactly in the focal plane of the grating. But if the plate is displaced inwards or outwards two lines arise, which become more blurred and the distance between the centers of which becomes greater, the more the plate is displaced from its proper position. The lines exchange positions, right and left, whenever the true focal plane is passed. According to this explanation the distance A between the centers of the images is related to the error B of the adjustment of the plate as half the breadth of the grating G is to the radius of curvature R; or $A = \dfrac{BG}{R}$. If the sources of light were still more incorrectly placed, so that,

for instance, only the first and last third of the grating were illuminated by them, G would be equal to two-thirds of the grating width, etc.   Now, I have attempted to ascertain by experiment how great B can be made in practice without producing a perceptible falling off in the sharpness of the lines.   The result shows, I believe, that an error of adjustment of 1^{mm} cannot be observed when the grating is fully illuminated, and that with errors of even 2^{mm} and 3^{mm} the plates are still serviceable.   If, however, the grating is not fully illuminated, the cone of rays becomes narrower, the lines therefore much sharper, and serviceable plates will be obtained with even twofold or threefold greater values of B.   For my grating the breadth is 140^{mm}, and $R = 6500^{mm}$.   Assuming that the two halves or the two outer thirds are illuminated, a displacement of 0.2 tenth-meters ($0^{mm}.1$ on the plate) would require values of B respectively equal to 9^{mm} and $6^{mm}.5$, which are certainly improbably large, but not impossible.   Most of the displacements that I have observed are at most only half as great as that assumed above, and thus are quite well explained in this manner.

In their researches on the spectrum of clèveite gas, Runge and Paschen[1] have observed similar displacements, which they ascribe to the astigmatism of the image, and which they seek to avoid by causing both sources of light to illuminate the same short length of slit.   In fact, if we suppose that the slit is somewhat curved, and that 1^{cm} of it is illuminated by one of the sources, while a length of 1^{mm} is illuminated by the other, the image of the first source will be displaced, since every point of the slit is represented by a line 15^{mm} or 20^{mm} long in the image. Nevertheless I find it impossible to accept this explanation in the case of the displacements which I have observed, since it would imply very bad definition of the lines.   If the middle of a line as measured were 0.2 tenth-meters out of place, the breadth of the line would be increased by 0.4 tenth-meters ; *i. e.*, the line would be greatly blurred, which was not the case in my experiments.   However, it is quite probable that the explana-

[1] *Ap. J.*, **3**, 6, 1896.

tion of Runge and Paschen, which is undoubtedly theoretically correct, applies to the extreme cases which I observed, so that the error of adjustment was not necessarily so large as the value computed above.

I have considered these circumstances so fully, because they are of fundamental importance in connection with the exact measurement of gaseous spectra. The difficulties vanish when the sources of light are so broad that the whole grating is illuminated. For this reason the method used by Kayser and Runge, of forming an image of the Geissler tube on the slit by means of a lens, is greatly to be recommended, as the more divergent cone of light so obtained completely fills the aperture of the grating. However, only a few of my latest photographs were obtained in this manner.

After I had ascertained the cause of these appearances, I adjusted the plate with the greatest care, and placed the iron spark and Geissler tube in such positions that the grating was fully illuminated. Results were then obtained which were in excellent agreement, and which I regard as correct. The plates with displaced lines thereupon became available, since the wavelengths could be corrected by the addition of a constant. A beautiful confirmation of the correctness of the wave-lengths was also found; on a plate taken with a quartz tube the two aluminium pairs at λ 3961, 3944 and λ 3092, 3082 appeared among the argon lines, and their deduced wave-lengths agreed with the measures of Rowland.[1]

As normal lines were exclusively used lines measured by Rowland. An idea of the accuracy which was attained can best be formed with the aid of the separate measures for a number of lines. I select for this purpose the strongest group in the red spectrum.

λ 4158.734, 692, 736, 716, 711, 690, 715, 733, 719, 700, 711, 708, 700, 713, 717.

[1] This presence of the aluminium lines seems to me to be of interest on other grounds, since I do not know of any case in the literature of the subject where the lines of the electrodes are visible in the spectra of Geissler tubes. Perhaps the lines of other metals may also be obtained in argon, thus allowing the determination of their wave-lengths at low pressure.

λ 4162.941, 866, 904, 885, 933.

λ 4164.309, 323, 317, 281, 293, 293, 316, 326, 327, 319, 314, 309, 306, 295, 292.

λ 4182.007, 997, 010, 977, 978, 993, 022, 017, 000, 971, 017, 012, 000, 009, 011.

λ 4190.846, 831, 868, 853, 844, 830, 824, 853, 838, 821, 857, 824, 841, 838, 851, 838.

λ 4191.168, 194, 167, 149, 126, 146, 163, 149, 193, 151, 183, 162, 153, 171, 162.

λ 4198.452, 443, 457, 420, 435, 414, 433, 463, 424, 419, 443, 432, 440, 433, 432, 441.

λ 4200.814, 781, 802, 790, 796, 767, 802, 830, 765, 782, 785, 802, 800, 804, 791, 807.

In the following table I give for each line the number of observations of which the mean is taken, and the mean error.

In the red spectrum I have only been able to completely photograph the region between the wave-lengths 3319 and 4792. The spectrum has only a few lines of short wave-length, which I have measured on rather poor plates, so that the mean error may be about 0.1 tenth-meter. Above λ 2967 I have obtained no argon lines in the red spectrum; on one tolerably sharp negative made with seven hours' exposure and a very strong current appear only the silicon lines and the mercury line λ 2536. Of the lines having a greater wave-length than 4702 I have several times obtained only the strongest, as far as λ 5912, on plates with sharp definition, and I therefore give the wave-lengths to only 0.01 tenth-meter.

Since the remaining red, yellow and green lines were required for my investigation of the spectrum with reference to the law governing the distribution of the lines, I sought to determine their wave-lengths by means of a plane grating and a spectrometer, and these measures are included in the list, although the results are given to the nearest 0.1 tenth-meter only. They are means of three or four measures, which generally agreed to within 0.1 tenth-meter. The photographically determined lines in the first and second orders were used as normal lines for computing the results of the visual measures.

My photographic measurements in the stronger blue spectrum extend from $\lambda\,2762$ to $\lambda\,5145$, although the shortest wavelengths are deficient in accuracy, as they were measurable on only one or two plates. Here also the few lines lying still further toward the red were supplied by ocular measures.

The measurements of the spectra of argon which have hitherto been published were made by Crookes,[1] with a prism spectroscope, and by Eder and Valenta,[2] with a small concave grating, but in neither of these investigations is the blue divided from the red spectrum. Crookes gives many lines as common to both spectra; Eder and Valenta give the red spectrum between $\lambda\,3319$ and $\lambda\,5060$, and designate a number of lines as occurring in the blue spectrum also. I have included in the following list the measures taken from both papers, for comparison with my own. The first column in the table contains the wave-length, the second the approximate intensity, 1 representing the faintest and 10 the strongest line; the third column gives the number of observations, the fourth the mean error, the fifth and last the measures of Eder and Valenta (E) and of Crookes (C).

A comparison of my results with those of Eder and Valenta reveals a very satisfactory agreement; the differences rarely exceed a few hundredths of a tenth-meter, and this may probably be regarded as the highest accuracy attainable with a grating of $0^{\mathrm{m}}.75$ radius, such as was used by Eder and Valenta. The errors in Crookes' work are naturally much greater; they reach several tenth-meters. Some of the striking differences are the following: Crookes has in the red spectrum the lines $\lambda\,3904.5$, intensity 8, and $\lambda\,5746$, intensity 6, which do not occur at all in my table. Eder assigns to the line $\lambda\,3900.04$ the intensity 8, while I have given it the intensity 1. In the blue spectrum Crookes gives a line $\lambda\,4938$ with intensity 10, which, according to my observations, does not exist; Runge and Paschen also have not seen this line.

[1] *Chem. News*, **71**, 58, 1895.

[2] *Anzeiger Wien. Akad.*, **21**, 1895.

I.   RED SPECTRUM OF ARGON.[1]

λ	Intensity	No. of Obs.	Mean Error			λ	Intensity	No. of Obs.	Mean Error	
2967.35	5	1	100			3567.789	4	10	007	3567.84 E 3566.5 C
2968.39	2	1	100			3572.416	2	6	009	3571.89 E
2972.60	1	1	100			3599.822	1	2	036	
3021.52	4	1	100			3606.677	5	11	012	3606.77 E 3605.0 C
3125.70	4	2	030			3632.766	3	9	015	3632.83 E 3632.5 C
3131.90	2	2	010			3634.586	3	8	013	3635.60 E
3175.11	1	1	100			3643.227	2	5	011	3643.27 E
3244.51	1	1	100			3650.258	2	14	018	3649.95 E
3295.44	2	1	100			3654.962	1	6	017	
3302.50	3	2	020			3659.632	2	9	007	3659.70 E
3303.08	1	1	100			3663.392	1	5	010	
3319.459	3	4	005	3319.35 E		3670.783	2	9	007	3670.81 E
3325.626	2	4	027			3675.353	1	6	007	3675.38 E
3341.637	1	2	009			3691.001	2	9	007	3691.07 E
3360.146	1	4	045			3696.587	1	6	030	3696.66 E
3373.586	2	4	018	3373.64 E		3738.030	1	2	003	3738.03 E
3381.573	1	2	054			3743.808	1	2	015	3743.89 E
3387.698	1	2	036			3770.440	3	10	019	3770.81 E 3771.5 C
3388.464	1	2	015			3775.476	1	2	018	3775.62 E
3389.955	1	2	015			3781.461	2	9	010	3781.46 E
3392.885	2	2	009	3392.99 E		3801.049	1	2	018	
3393.848	3	6	005	3393.90 E		3834.768	4	8	010	3834.83 E 3835.5 C
3398.016	1	2	005			3850.693	1	3	030	3850.70 E
3406.287	1	2	018			3866.353	1	2	007	3866.44 E
3442.640	1	2	036			3894.795	2	3	015	3894.76 E
3455.076	1	2	009			3900.065	1	2	026	3900.04 E
3461.192	3	6	006	3461.21 E		3947.645	4	12	010	3947.70 E
3476.894	1	2	005	3476.94 E		3949.107	6	13	007	3949.13 E 3948.5 C
3493.435	1	2	030			4044.565	7	16	006	4044.56 E 4044.0 C
3506.650	2	6	021	3506.59 E		4046.027	2	2	036	4046.01 E
3509.934	1	2	036			4046.620	2	4	015	
3514.513	1	2	060	3514.67 E		4054.663	2	7	021	4054.68 E
3545.947	1	3	016	3545.87 E		4154.657	2	4	009	4156.6 C
3554.435	5	11	007	3554.47 E 3554.5 C		4158.722	9	15	004	4158.63 E 4159.5 C
3556.135	2	4	005	3556.16 E		4162.906	1	5	014	
3559 601	1	3	036	3559.66 E		4164.309	5	15	004	4164.36 E 4164.5 C
3563.362	3	9	018	3563.46 E 3562.8 C		4182.002	5	15	004	4182.07 E 4183.0 C
3564.423	3	9	007	3564.48 E		4190.841	5	16	003	4190.76 E 4191.5 C

[1] In accordance with the resolution of the Editorial Board of THE ASTROPHYSICAL JOURNAL, this table is arranged so that it begins with the short wave-lengths. In my opinion, however, the choice is a very unfortunate one. Series in spectra invariably run from red toward blue, the numbers determining the order of pairs and triplets increasing, and the intensity diminishing in this direction. Hence the table would naturally run in the reverse direction; for example, the hydrogen spectrum naturally ends with *Ha* instead of beginning with it. While there is yet time it may perhaps be advisable to alter this decision.

λ	Intensity	No. of Obs.	Mean Error			λ	Intensity	No. of Obs.	Mean Error	
4191.841	5	16	005	4191.15 E		5606.84	5	3	030	5610 C
4198.162	5	15	003	4198.42 E	4198.0 C	5650.90	4	2	010	5651 C
4200.799	9	16	004	4200.76 E	4201.0 C	5659.4	1			
4205.007	1	4	012			5683.0	1			5683 C
4251.329	3	8	008	4251.25 E	4251.5 C	5690.1	1			
4259.491	7	14	006	4259.42 E	4259.5 C	5772.5	1			5771 C
4266.425	5	14	006	4266.41 E	4266.0 C	5802.4	1			5803 C
4272.304	6	14	005	4272.27 E	4272.0 C	5832.3	2			5834 C
4300.249	6	13	005	4300.18 E	4300.5 C	5860.6	2			5858 C
4304.033	1	2	030			5882.78	2	2	020	
4333.714	6	13	005	4333.64 E	4333.5 C	5888.93	3	2	041	5887 C
4335.491	4	11	006	4335.42 E		5912.22	4	2	025	5909 C
4345.322	4	11	006	4345.27 E	4345.0 C	5928.5	2			5926 C
4363.970	1	3	015	4363.93 E		5943.5	1			
4510.851	5	8	c18	4510.83 E	4509.5 C	5987.5	1			
4522.389	3	4	018	4522.45 E	4514.0 C	5999.5	1			
4596.205	3	4	008	4596.25 E	4594.5 C	6013.6	1			
4628.623	3	3	010	4628.66 E	4629.5 C	6025.8	1			
4702.504	4	3	039	4702.38 E	4701.2 C	6031.5	5			6038 C
4732.4	1					6043.0	4			6045 C
4738.2						6052.7	2			
4768.3	1			4768.80 E		6059.5	4			6056 C
4807.8	3					6098.8	1			
4849.9	1					6106.1	2			6099 ? C
4882.3	2				4879 C	6145.6	2			6143 C
4889.4	1			4888.27 E		6155.2	1			
4969.6	1				4965.5 C	6170.3	1			
5010.4	2				5012 C	6172.9	2			6173 C
5051.3	1					6212.5	2			6210 C
5063.2	2				5065 C	6217.5	1			
5120.0	1					6296.8	2			6302 ? C
5152.7	3					6307.8	1			
5162.6	4				5165 C	6368.0	1			
5188.46	5	2	016		5185.8 C	6384.5	2			6377 ? C
5221.9	2				5222 C	6415.2	5			6407 C
5254.4	2				5258 C	6676.5	3			6664 C
5275.3	1					6752.7	3			6754 C
5412.8	1					6786.5	1			
5421.9	2				5421 C	6870.6	1			
5442.1	1				5444 C	6937.8	1			
5451.87	3	2	020		5456 C	6964.8	8			6965.6 C
5458.2	1					7029.2	1			
5496.02	4	5	031		5496.5 C	7066.6	7			7056.4 C
5506.7	1				5501 C	7146.8	1			
5525.2	1				5520 C	7271.6	1			7263 C
5558.80	5	3	080		5557.0 C	7383.9	2			7377 C
5572.71	3	2	010		5567 C	7503.4	2			7506 C
5581.3	1					7515.1	2			
5589.4	1					7635.6	2			7646 C
5599.6	1					7723.4	2			

2. BLUE SPECTRUM OF ARGON.

λ	Intensity	No. of Obs.	Mean Error		λ	Intensity	No. of Obs.	Mean Error	
2762.11	3				3210.678	1	2	027	
2774.90	1				3212.737	1	2	015	
2796.66	2			2794.4 C	3222.183	1	2	004	
2824.47	1			2830.2?C	3236.812	1	2	016	
2842.88	2				3237.920	1	2	021	
2853.27	1				3243.845	4	4	013	
2855.29	3				3245.638	1	3	018	
2878.79	2				3249.972	4	4	014	
2884.24	5				3251.888	3	3	005	
2891.73	2				3263.722	2	4	010	
2896.91	1				3263.953	1	3	008	
2924.68	1				3271.122	1	3	033	
2931.52	2			2929.6 C	3273.476	1	3	012	
2942.94	5			2942.7 C	3281.867	3	4	010	
2955.37	2				3282.661	2	3	005	
2979.16	4			2978.6 C	3285.913	8	4	004	
3000.63	2			2998.2 C	3289.201	2	3	009	
3002.67	4				3293.768	4	3	010	
3024.078	3	2	021		3298.652	2	3	010	
3027.181	1	2	012		3301.938	7	4	007	
3029.015	2	2	021		3305.249	2	3	005	
3031.759	1	2	009		3305.720	1	3	010	
3033.620	2	2	009		3306.499	1	3	010	
3039.477	1	2	050		3307.368	3	3	008	
3046.130	1	2	005		3308.040	1	3	016	
3048.552	1	2	027		3311.318	6	4	007	
3054.846	3	2	010		3314.622	1	2	027	
3064.830	2	2	012	3064.7 C	3323.671	2	2	006	
3066.998	1	2	005		3327.441	1	2	012	
3078.212	2	2	005		3332.972	1	2	005	
3083.720	1	2	005	3084.8?C	3336.269	6	3	010	
3093.478	3	2	005	3092.7 C	3339.602	1	2	012	
3110.441	1	2	005		3341.518	1	2	012	
3116.162	1	2	006		3342.532	1	2	012	
3125.980	1	2	005		3344.857	6	3	010	
3127.996	1	2	008		3348.161	1	2	006	
3139.156	3	2	004		3351.112	3	3	005	
3157.577	2	2	004		3352.248	2	2	005	
3161.519	3	2	009		3355.298	1	2	006	
3165.480	1	2	005		3358.633	6	3	005	
3169.812	4	2	006		3361.418	2	2	008	
3171.767	1	2	024		3361.973	1	2	008	
3181.174	3	2	007		3365.660	1	3	015	
3183.171	1	2	012		3366.758	1	3	015	
3187.970	1	2	005		3371.077	1	2	018	
3194.400	1	2	004		3376.618	3	2	008	
3196.109	1	2	015		3379.674	1	2	034	
3204.469	2	2	012		3388.706	4	3	019	3388.0 C

λ	Intensity	No. of Obs.	Mean Error			λ	Intensity	No. of Obs.	Mean Error	
3391.959	4	3	019			3548.680	2	7	018	
3404.432	1	2	015			3555.107	1	2	021	
3413.665	1	2	008			3556.167	1	2	022	
3417.608	1	2	008			3557.029	1	2	022	
3421.821	2	3	011			3558.670	1	2	022	
3424.385	1	2	009			3559.695	8	9	009	3559.66 E 3558.2 C
3429.846	1	3	027			3561.213	7	9	006	3561.13 E 3560.0 C
3430.650	1	4	013			3562.388	1	2	009	
3438.174	2	2	009			3563.198	1	2	009	3563.46 E
3445.254	1	2	010			3564.586	1	2	045	
3450.223	1	2	006			3565.221	2	8	006	3564.0 C
3454.298	2	5	010	3453.5 C		3573.290	1	2	045	
3455.572	1	2	006			3576.808	8	10	007	3576.79 E 3575.0 C
3464.364	2	5	020			3579.000	1	2	015	
3466.533	2	5	018			3580.439	1	3	009	
3471.443	1	2	018			3581.802	4	10	007	3581.83E } 3580.3C
3472.713	1	2	018			3582.547	7	10	007	3582.51E }
3473.368	1	2	006			3585.203	1	4	045	
3476.926	5	6	005	3476.94 E 3475.7 C		3586.122	1	2	030	
3478.410	2	6	006			3587.122	1	2	030	
3480.636	5	6	006			3588.633	9	9	007	3588.58 E 3587.0 C
3484.121	1	2	012			3592.198	1	5	031	
3488.316	1	4	021			3603.981	1	2	015	
3491.030	2	5	012			3606.056	2	8	010	3605.0? C
3491.440	5	6	010	3490.0 C		3622.354	2	7	010	3617.5?C
3491.723	7	6	006	3491.71 E		3637.212	1	3	010	
3493.562	1	2	005			3638.015	7	10	010	3631.7?C
3495.193	1	4	015			3640.022	2	9	007	
3497.219	1	2	033			3650.313	1	2	024	
3498.419	1	3	045			3651.141	1	7	030	
3499.815	3	5	008			3655.474	3	9	005	
3500.724	1	2	006			3656.270	1	9	022	
3502.841	2	4	008			3660.635	1	9	009	
3503.730	2	7	008			3669.700	1	5	044	
3506.426	1	2	009			3670.071	1	2	015	
3507.268	1	2	008			3678.478	2	8	008	
3507.795	1	2	015			3680.124	1	6	030	
3509.475	3	6	010			3692.739	1	4	021	
3509.961	3	6	010			3696.160	1	2	022	
3511.286	8	6	005	3508.8?C		3710.167	1	2	024	
3511.804	1	4	010			3712.941	2	4	024	
3514.351	4	4	008	} 3514.67E 3513.5C		3714.744	1	3	024	
3514.576	4	5	016			3716.704	1	4	024	
3518.079	1	4	036			3717.367	1	8	017	
3520.191	3	7	012	3519.2 C		3718.403	3	11	005	3718.39 E 3718.0 C
3521.431	2	7	015	3520.5 C		3720.617	1	10	010	
3522.100	1	6	019			3724.697	2	7	027	
3535.514	3	6	012	3534.3 C		3725.665	1	4	060	
3545.792	5	7	016	3545.87 E 3544.5 C		3729.450	9	12	007	3729.44 E 3729.8 C
3546.005	5	7	021	3546.07 E 3547.5?C		3733.122	1	2	014	

λ	Intensity	No. of Obs.	Mean Error		
3735.542	1	2	048		
3738.094	3	11	004	3738.03 E	3738.5 C
3747.135	1	2	039		
3750.428	1	3	010		
3753.722	1	8	019		
3756.541	1	4	012		
3763.715	3	9	008		
3765.463	5	12	006	3765.43 E	3766.0 C
3766.286	2	11	012		
3770.719	2	10	010	3770.81 E	3770.5 C
3776.885	1	3	010		
3781.018	6	12	004	3781.07 E	3780.8 C
3786.536	2	10	015		
3795.509	3	9	009		
3796.882	1	3	036		
3799.596	2	9	015		3799.5 C
3800.429	1	3	060		
3803.381	2	9	006		3803.5 C
3808.746	1	6	015		
3809.649	3	9	005	3809.58 E	3809.5 C
3819.300	1	3	093		
3825.865	1	5	020		
3826.976	3	10	008		3827.5 C
3830.585	1	6	040		
3841.709	1	5	015		
3844.921	1	6	014		
3845.535	1	6	016		3845.5 C
3846.860	1	3	006		
3850.715	8	11	006	3850.70 F	3851.5 C
3854.522	1	3	042		
3855.366	1	2	033		
3856.210	1	4	034		
3858.456	2	6	009		
3868.718	6	11	007	3868.68 E	3868.5 C
3872.326	2	7	013		3871.8 C
3874.288	1	3	040		
3875.406	3	10	008		3875.5 C
3880.432	1	4	039		
3891.550	2	8	009		
3892.128	4	9	009	3892.10 E	3892.0 C
3900.763	2	8	022		
3907.896	1	2	090		
3911.721	1	6	022		
3914.931	3	9	018	3914.93 E	3915.0 C
3924.798	1	2	035		
3925.903	3	8	009	3925.98 E	3927.5 C
3928.749	7	11	009	3928.82 E	3928.5 C
3931.382	2	9	016		
3932.717	4	9	008	3932.71 E	3931.8 C
3937.208	1	3	039		
3944.409	4	9	005		3943.5 C
3946.290	4	10	009		
3952.892	1	6	013		
3958.529	2	3	013		
3960.591	2	7	021		
3968.496	4	11	006	3968.54 E	3967.8 C
3974.646	2	7	021		
3974.859	1	2	018		
3979.541	3	11	009		3978.5 C
3988.378	1	5	018		
3992.196	2	10	008		
3995.035	1	2	060		
4010.052	1	2	030		
4011.527	1	2	045		
4014.002	6	12	006	4013.97 E	4013.0 C
4017.986	1	2	015		
4023.730	1	3	044		
4034.022	2	9	010		4033.0 C
4035.624	2	9	006		
4038.966	2	8	010		
4043.039	4	12	009	4043.02 E	4044.0 C
4053.111	1	5	010		
4068.171	1	2	045		
4072.159	7	11	007	4072.15 E	4072.5 C
4072.579	3	9	010		
4076.854	2	6	012		
4077.204	2	5	015	4077.47 E	
4079.712	2	9	010	4079.83 E	
4080.872	1	2	027		
4082.535	2	9	012	4082.59 E	
4089.041	1	3	021		
4097.265	1	2	090		
4099.602	1	2	018		
4104.107	7	10	016	4104.10 E	4105.0 C
4112.916	1	5	039		
4131.913	4	7	009	4131.95 E	4131.5 C
4146.761	1	2	030		
4156.295	2	6	013		
4178.504	1	2	027		
4179.479	1	4	003		
4183.106	2	3	019		4183.0?C
4189.774	1	2	022		
4202.106	2	4	015		
4203.609	1	4	036		
4218.843	3	5	006		
4222.839	3	6	015		
4227.146	2	4	018		
4228.310	5	8	007	4228.30 E	4228.5 C
4229.015	1	2	036		
4229.813	1	2	063		

λ	Intensity	No. of Obs.	Mean Error		
4237.395	3	6	010		
4266.684	6	9	006	4266.41 E	4266.0 C
4275.327	1	4	014		
4277.718	6	8	004		4277.0 C
4283.054	3	7	015		
4298.222	1	2	015		
4300.824	2	7	012		4299.0?C
4309.311	2	7	020		
4331.354	6	10	007	4331.31 E	4333.5 C
4332.205	3	9	005	4332.15 E	
4337.244	1	3	015		
4343.904	2	5	013		
4348.222	10	9	007	4348.11 E	4348.5 C
4352.368	4	9	007		
4362.229	2	5	018		
4367.952	1	5	033		
4370.928	4	9	009	4370.89 E }	4369.0 C
4371.504	4	9	009	4371.46 E }	
4375.201	1	3	090		
4376.112	3	6	030	4376.15 E	
4379.827	6	9	005	4379.79 E	4376.5 C
4383.900	2	2	020		
4400.271	3	7	003	4400.20 E }	4399.5 C
4401.156	5	9	006	4401.17 E }	
4408.095	1	3	012		
4421.113	1	6	015	4421.06 E	
4426.165	9	9	005	4426.15 E	4422.5 C
4430.355	6	9	006	4430.35 E	4426.5 C
4431.172	4	9	005	4431.13 E	
4434.037	2	6	018		
4439.539	1	4	030		
4443.545	1	2	005		
4449.123	2	4	013		

λ	Intensity	No. of Obs.	Mean Error		
4460.682	2	4	036		
4475.015	2	4	019	4475.15 E	
4482.003	5	6	015	4482.03 E	4478.3 C
4503.111	1	2	012		
4545.220	5	4	007	4545.28 E	4543.5 C
4579.527	5	4	007	4579.49 E	4579.5 C
4590.081	5	5	009		4586.9 C
4609.742	6	7	005	4609.69 E	4608.0 C
4637.351	2	2	050		
4658.079	4	3	005	4658.01 E	4656.5 C
4727.027	4	4	008	4726.96 E	4726.6 C
4736.065	5	4	012	4736.03 E	4734.5 C
4765.028	3	5	013	4764.99 E	4763.0 C
4806.173	6	6	007	4806.10 E	4805.0 C
4847.963	3	6	012	4847.95 E	4847.5 C
4880.004	4	6	009		4879 C
4933.406	1	2	009		4938 C
4965.239	2	4	015		4965.5
5009.426	2	3	060		5007 C
5017.331	1	2	030		5012 C
5062.189	2	3	012		5065 C
5141.909	1	1			5140 C
5145.565	2	2	060		
6114.1	3				6120 C
6140.9	1				
6172.3	3				6173 C
6215.6	1				
6243.7	2				6232 ?C
6482.8	1				
6638.6	2				6628 ?C
6644.2	3				
6684.2	3				

The estimated intensities, according to the three observers, differ very considerably. My own estimates agree better with those of Crookes than with those of Eder and Valenta. I do not, however, attach much importance to this fact; such estimates are always very uncertain; they are influenced by the character of the apparatus and by the kind of plate which is used, and it is very likely that the intensities vary with the pressure and current strength. Since neither Crookes nor Eder and Valenta have obtained the two spectra completely separated, their conditions were different from mine, and in many cases

the intensities which they observed may actually have been different from my own.

I have done a great deal of work in searching for series of related lines. Although, on account of the very large number of lines, such an inquiry was by no means promising, its value would have been great if at least some indications had been found as to whether we have to deal with a single element, and if so, as to the place in the natural scale to which it belongs. Unfortunately my labors in this direction have been unsuccessful. No pairs or triplets whatever are found in the blue spectrum, although in the red spectrum I have found three triplets, as follows :

λ	$\frac{1}{\lambda}$	Difference
4702.504	2126527	
		33943
4628.623	2160470	
		15238
4596.205	2175708	
4363.970	2291491	
		33956
4300.249	2325447	
		15210
4272.304	2340657	
4251.329	2352206	
		33950
4190.842	2386156	
		15203
4164.309	2401359	

Here, as we should expect from the triplets observed in other elements, the vibration difference between the first and second lines is about twice as great as that between the second and third ; but the intensities do not vary regularly, so that I can attach no importance to these three triplets. The chemical nature of argon is therefore not revealed by spectrum analysis. I desire, nevertheless, to emphasize the fact that I have observed nothing which can lead to the conclusion that argon is a mixture of several elements.

BONN, April 1896.

A NEW POINT OF VIEW FOR REGARDING SOLAR PHENOMENA, AND A NEW EXPLANATION OF THE APPEARANCES ON THE SURFACE OF THE SUN.

By J. Fényi.

It is known to all that the nature of the central body of our system is still shrouded in the greatest obscurity, and this, the nearest fixed star, offers many problems but few solutions. The phenomena lie clearly before us, but the attempted explanations of their significance are full of contradictions. The latest theories convey to us an impression of the despair which seeks to escape difficulties by every possible path. Such a difficulty is encountered in the enormous atmosphere of the Sun, which may be implied from the height to which the prominences rise, and which in the course of a solar eclipse may actually be seen. In opposition to such evidence as this, calculation shows that a large heavenly body, other things being equal, should have a shallow atmosphere, and that a height which approximates to the radius of the Sun would produce an enormous pressure on its surface, contradicted by observations of the lines of the spectrum. The spectroscope reveals enormous disturbances in this mighty atmosphere, rejected by many observers as incredible. But a sound investigation must not leave the secure basis of observation. Motions on a vast scale appear in such overwhelming evidence that up to the present no observer of the Sun has been found who has been willing to join with the recent theorists. In what follows attention is directed to a new point of view which heretofore has entirely escaped notice, and from which solar phenomena take on a natural and simple aspect, freed from the obstruction of the most obstinate of the contradictions that have been referred to above.

Solar theories are apt to be regarded with the greatest mis-

trust   It is not my intention to add a new one to their number, but merely to give due stress to certain conclusions which follow from the application of established physical laws to the facts of observation.

The following investigations postulate only two assumptions : the first is that enormous velocities, which observations of prominences reveal, are in fact movements of matter.   It is an axiom of sound logic that what is seen must be accepted as real until it is shown that a delusion exists which requires a different interpretation of the phenomenon. The second assumption is that the phenomena displayed by the prominences take place in free space.   The following investigation is intended to prove that this assumption also is justifiable.   The greatest difficulties will thus be removed without creating new ones.

Let us consider the case of a globe of hydrogen whose temperature is 10000°, suddenly transported into free space (by free space is only meant such space as that in which the planets move).   Let the radius of this globe be 5800^{km}; its volume will be about that of the Earth, and at the distance of the Sun its apparent diameter will be $16''$, and it will present the appearance of a small prominence cloud to an observer.   The globe will naturally tend to expand with explosive force; the velocity, however, with which the first layer tends to move off is nevertheless limited, being equal to the theoretical velocity with which the assumed gas diffuses in free space.   Computation makes it 9250^{km} per sec.   It is obvious that this speed cannot be compared with the velocity of the protuberances.   It is, however, evident that this motion cannot spread instantaneously throughout the entire globe; a certain time will be required for the process of expansion to reach the center.   The velocity with which the expansion spreads cannot be greater than the velocity with which a difference of pressure in the assumed gas would be transmitted.   Here again the purely theoretical formula is to be applied, omitting the coefficient which expresses the relation of the specific heat with constant pressure to that with constant volume; we thus obtain the velocity of 6581^{m} per second.

From this, however, the important result is obtained that it will take fully 14^m 41^s for the process of expansion to reach the center. This time may be briefly designated in what follows as the interval of expansion. Accordingly, 7^m after the hypothetical globe is transported into free space there will be within it a globe whose radius is only one-half that of the assumed globe, which has not yet been reached by the expansion, and which will therefore shine with unchanged brightness.

This interval of 7^m is in itself more than sufficient to explain the visibility of eruptive prominences. As an illustration I may here cite the prominence which I observed September 30, 1895, and fully described in The Astrophysical Journal for March 1896, p. 192. The small clouds which reached the highest positions were found according to careful measurements to be $472''$ high at 10^h 23^m $44^s.0$; 6^m later, that is to say at 10^h 29^m $23^s.0$, they had attained a height of $688''$ and then disappeared. If these clouds, which were about the size of our globe, had also been at a temperature of $10000°$, they might have entered free space at an altitude of $472''$ and would still have remained visible at least 6^m, or until they had reached the height of $688''$. Similar cases were observed on other occasions.

The observed phenomena of eruptive prominences can be explained without difficulty, if we assume that masses of hydrogen are ejected beyond the atmosphere of the Sun into free space. The great velocity of the prominence does not allow time enough for the complete expansion of the hydrogen while rising; in fact the expansion does not even reach the interior. In the case of such an enormous mass the molecular forces, even at such high temperatures, have only a secondary importance. The gases are to be regarded as compact masses comparable, say, to drops of rain, which may indeed evaporate on their outer surface, but do not disappear. We are therefore by no means compelled to attribute the same height to the atmosphere of the Sun which the prominences occasionally reach.

It is true that the atmosphere has been assumed to be very rare,—in fact inconceivably so; but its great height has always

been accepted.   As one proceeds outward without limit, a state
of rarification is reached which is practically the same as a total
absence of an atmosphere ; an atmosphere the presence of which
cannot be recognized in any way, is a superfluous hypothesis.
According to different calculations the atmosphere of the Sun
must certainly extend to a great height, although not necessarily
above the photosphere.   We may assume its bottom to be far
below the latter.   If, however, it is preferred to hold fast to the
idea of an exceedingly rare atmosphere extending to a consider-
able height above the photosphere, then it is shown in the preced-
ing paragraph that it is by no means necessary to attribute to
the prominences existing in it an inconceivable tenuity, which,
in consideration of their rapid ascent, is moreover quite impos-
sible.   In fact we may attribute to the prominences in free space
any density we choose; the process of dispersion will never-
theless have the same rapidity, the duration of visibility of the
phenomenon will be the same, for the velocity with which the
expansion spreads is independent of the density of the gas.
The expansion interval varies directly with the diameter of the
mass and is inversely proportional to the square root of the
absolute temperature.   If we assume a diameter of $64''$ for the
hypothetical gaseous sphere, it will merely represent an ordinary
prominence ; but it will be fully an hour before the expansion
reaches the center.   On the other hand a temperature of $40000°$
would reduce the expansion interval one-half; higher tempera-
tures are therefore attended by more rapid dissolution, but not
by a longer duration of visibility of a prominence.

A very striking characteristic of eruptive prominences is thus
explained.   I have, for instance, always noticed that the faster
a prominence ascends the more rapidly it is dissolved.   We are
therefore justified in attributing a higher temperature to eruptive
prominences, both because they come from a greater depth,
and because, on account of their more rapid rising, they must
reach the surface with a higher temperature than those of the
ordinary type.   Their higher temperature is also shown by their
unusual brightness.   A higher temperature thus explains the

more rapid dissolution, whereas, on the assumption that the prominences are cooled by adiabatic expansion in an atmosphere, a longer duration of visibility would be expected.

The explanation of the phenomena here given finds an excellent confirmation in the way in which a detached floating prominence tends to disintegrate. During the ten years of my observations I have witnessed and carefully observed any number of such occurrences. The dissolution does not take place by the enlargement and consequent fading of the prominence, as would necessarily be the case if the elastic expansion extended throughout the mass; but the prominence disappears from without inwards, just as our own clouds dissolve. Even if the brightness does thereby pale, this fact is explained by the decrease of the luminous area with the decreasing diameter. With our conception of these phenomena, we are in a position to assign the temperature of a free floating prominence. It is only necessary to follow the process of dissolution with the proper measurements in order to determine the velocity with which the expansion of the gases travels toward the interior; for this is, according to the following formula, dependent on the temperature only. We have:

$$V = \sqrt{\frac{pT}{d\,273}}$$

in which p is the pressure, d the density of the gases expressed in suitable units, T the absolute temperature, and V the velocity with which the process of dissolution proceeds. We thus obtain a value which, it is true, is somewhat uncertain, inasmuch as other circumstances may modify the visibility, but from which we are nevertheless enabled to arrive at some conclusion respecting the temperature of the Sun; for since the prominence has not time to expand, it cannot cool; it must therefore reach its elevated position with the same temperature it had when it left the surface.

It is noteworthy that the temperature of 10000° adopted above gave an expansion interval which agreed quite well with observation. The extent of the prominence fragments was not measured, but merely estimated from memory; but even if we

assume the temperature to have been nearer 20000°, the result must be regarded as a valuable one, when we consider that estimates of the temperature are really nothing better than assumptions, and that they vary from 3000° to 5000000°.

The influence of an elastic expansion is not intended to be denied, or excluded from this discussion. In reality the prominences are not transferred into free space in an instant, but must rise from the lower strata to the higher where the pressure is less, and must therefore assume a corresponding state of expansion, which, after they enter free space, will retard the disappearance of the phenomena by a simultaneous increase of volume.

Let us now return to our globe, which we left in a state of explosive expansion, in order to investigate whether the further expansion will raise any difficulties. The outermost layer will be dissipated into free space with a velocity of 9250^m per second in the direction of the radius of the globe. The heat corresponding to this kinetic energy can be derived from the displaced layer only, since the explosion has as yet left the interior undisturbed. Since no external work is done by this expansion, we can determine the heat by the energy equation according to which the sum of the potential and kinetic energy of every body, which neither receives nor loses energy, is a constant. If we call the mass of the stratum m, the velocity of the molecules at 10000° v, the molecular velocity remaining after the first instant of expansion W, the velocity with which the molecules are dissipated in free space V, we obtain the equation :

$$\frac{mv^2}{2} = \frac{mV^2}{2} + \frac{mW^2}{2}.$$

The temperature which the gases moving off into free space must assume at the first instant is given by W. It is :

$$W = \sqrt{\frac{T}{273}} \times 1848,$$

where 1848 is the velocity in meters of the hydrogen molecules at 0° C., and T the absolute temperature of the stratum. Substi-

tuting abc   the values applicable to this case, $v = 11335^m$, $V = 9250^m$, we obtain the temperature $3158°$ to which the stratum must suddenly fall in the first instant.   But even this cannot be maintained for an appreciable interval; the outflowing gas must continue to expand until the entire kinetic energy of the molecules is converted into molar motion.   The temperature will then approach absolute zero, the pressure will likewise approach zero, and the molecules thus dissipated will move off in free space with a velocity of 11335^m.   This complete conversion into energy of molar motion takes place quite rapidly; Hirn[1] showed experimentally that it is accomplished even in the exit tube of a gasometer.

This dispersive process involves one after another of the strata, as the expansion advances inward.   The outer strata do not interfere with the inner, since at any instant each outer stratum must have acquired a greater velocity than the next stratum within.

Although an absolutely free space has here been assumed, the essential features of the phenomenon have nevertheless been established with certainty, for obviously the circumstances cannot be materially affected by the assumption of any admissible density in interplanetary space, and a temperature of perhaps $-150°$ C.

If we wish to form some judgment as to the condition of a prominence rising within the atmosphere, we must above all take into consideration the enormous difference of pressure on the Sun.   In order to obtain a minimum value of this, than which a smaller value would be absolutely inadmissible, we will suppose that the same temperature exists throughout the whole atmosphere.   The differences of pressure at different altitudes are then given by the following formula:

$$p = p' e^{\frac{Gh}{RT}}$$

in which p' and p are the pressures at the upper and lower levels, G is the ratio of gravitation on the Sun to that on the Earth, R

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[1] *La cinetique moderne et le dynamisme de l'avenir*, p. 55.

the known constant of hydrogen, T the absolute temperature and h the height in meters. Substituting in the above the values $R = 422$, $T = 10000°$, $G = 28$; and imposing the condition that $p = 2\,p$, we obtain the result, that in an ascent of only 104^{km} the pressure will be decreased one-half. This result is applicable as long as the law of Gay-Lussac holds true. From it may be drawn the following important conclusions:

I. The pressure in the upper part of the chromosphere, or at an altitude of about $6''$, must be 10^{12} times less than that at its base.

II. The pressure at the apex of a prominence whose diameter is $16''$, or which is about the size of our assumed globe, must be 10^{22} times less than that at the base. Similar conditions of pressure must exist within the prominence itself, since the law also obtains at the depth where the prominence originated.

III. In consideration of the rapidity of ascent it is to be regarded as an established fact that no prominence can have a lower pressure at its center than that of any stratum previously occupied during its expansion. Let us again apply this to our globe of $16''$ diameter and $10000°$ temperature, to which we will allow the exceedingly small ascending velocity of 10^{km} per second. In accordance with an expansion interval of $14^m\ 41^s$ the globe must still have a central density corresponding to at least that of the solar atmosphere at a depth greater by 8810^{km}. This pressure must therefore be 10^{24} times as great as that of the surrounding atmosphere.

The last deduction unquestionably leads to the conclusion that such a prominence must be in a state of dissolution, just as if it were in free space. A smaller velocity than 10^{km} cannot in general be assumed in such a discussion of the observations, inasmuch as in free space the upper layer itself is dispersed with a velocity of 6^{km}. No ascending motion would therefore exist that could be detected by the observer, or the prominence would not be seen at all.

The view here set forth that the ordinary prominences are also in a state of continual dissolution, is so far supported by

observation that prominences of inferior height are seen to be constantly undergoing changes of structure while remaining in the same place. Their existence seems to be one of constant dissolution and renewal. This view naturally explains the usual and characteristic structure of most prominences; they present the appearance of a bundle of luminous pillars or vertical bands and threads, which are drawn out at their upper ends into the finest possible points. In the bands of light we see the streams of gas shooting upward; in the fine points their last remaining traces, vanishing as a result of the expansion,—and we see the same phenomena repeated in the grass-like points of the chromosphere.

EXPLANATION OF THE WHITE PROMINENCES AND THE CORONA.

The phenomena here investigated of expansion in free space above the Sun furnish a natural explanation of the phenomenon of the white prominences, which are only seen during total eclipses, surrounding the red prominences with an ill-defined envelope of silvery light. They are composed of the expanding gas of prominences, which, condensing into a mist, reflects the light of the Sun. This phenomenon follows as a necessary consequence upon the process of expansion of the risen prominence. The temperature of gas expanding in free space must approach absolute zero, until the tension of the gas becomes o; after which the cloud-like mass moves with the constant velocity of the rising prominence, increased by the velocity of the molecules, out into planetary space. The density of this fog, taking it in the more general sense of the ratio of the mass to the space in which it is contained, is by no means o. It is easily computed.

For this purpose we will consider the outside layer only, since the interior layers must pass through the same process. Using the same notation as before, the velocity of propagation of the expansion is given by the formula

$$V = \sqrt{\frac{pT}{d\,273}}.$$

If s be the thickness of the layer, we obtain for the time t in which the expansion is propagated through it the value

$$t = \frac{s}{V} \; ;$$

but during this time the molecules of the outer surface will have been dispersed with a certain velocity, representing the complete conversion of molecular into molar motion. This velocity of the molecules is given by the formula

$$V' = \sqrt{3 \; \frac{pT}{d\,273}}.$$

In the time t, therefore, the outermost molecules will have passed over the distance tV and the pressure of the layer is then

$$s + tV = s + \frac{s}{V}V'.$$

Substituting in this the radical expression above given

$$s + tV = s\left[1 + \sqrt{3} \; \right].$$

The layer under consideration has therefore become $1 + \sqrt{3}$ times thicker; its density consequently is only 0.366 the density of the prominence. As the derivation of this result shows, there exists between the density of the prominence and that of the cloudy mass resulting from its dispersion the constant ratio of 0.366, which is independent not only of the density and temperature of the gas at any time but also of its nature.

It would seem to be beyond question that if a prominence has sufficient density to be seen by its own light, the matter which it contains, diffused according to this ratio, must also be visible by reflected light. The brightness of the white prominence will accordingly be determined by the density of the parent red prominence, its extent by the temperature, its height principally by the velocity of ascension.

The density thus determined will subsequently be only gradually and slightly reduced, in proportion as the surface of the white prominence is increased by the divergent motions of the expanding gases. The matter endowed with the velocity above

determined will be projected in a definite form out into space; then it will come more directly under the influence of gravity, by which its radial velocity will gradually be checked, and by which the hydrogen, heated once more in the meantime by the solar radiation, will be drawn back upon the body of the Sun.

Since we have recognized the process of gaseous dispersion as active, not only in the lower prominences, but also in the points of the chromosphere, it follows that diffuse hydrogen must cause the Sun to be surrounded on all sides by a brilliant white envelope.

The views which we have held hitherto, with regard to the atmosphere of the Sun, must be considerably modified as a result of this explanation. If by the atmosphere of a heavenly body we mean the envelope of gas resting upon it, the solar atmosphere could hardly be regarded as extending more than a short distance above the chromosphere, which appears by direct observation to constitute such an envelope. Above it is found only dispersed hydrogen (with similar gases), which in its scattered condition gives a continuous spectrum, but which, when heated by the Sun, may easily and, in fact, must show the hydrogen lines; but this matter in no case constitutes an atmosphere, even though certain masses should assume a gaseous state, since these masses do not rest upon the body of the Sun, but gravitate toward the Sun, like cosmical bodies in free space. We may therefore appropriately call them gaseous meteors, which surround the Sun in every variety of form and circumstance of motion like an atmosphere. They constitute the corona.

Powerful eruptions, which are so strikingly distinguished from the ordinary prominences by the enormous scale of their motions, must of course furnish streams which pass far beyond the lower corona, and which are seen in the most capricious forms, especially in times of great solar activity. Their enormous length offers no difficulty, since eruptive prominences frequently give evidence of velocities which exceed even the potential of the Sun. Thus the prominence of September 30, 1895, above cited, had

still a velocity of 448^{km} at the height of $11'$, whereas the potential at this height is able to generate a velocity of only 409^{km}. This eruption must have produced a stream which extended indefinitely out into space in a straight line. Such streams have been observed during eclipses of the Sun.

This explanation of the corona finds a significant confirmation in the results which J. M. Schaeberle, Astronomer of Lick Observatory, reached in his comprehensive investigations of the outer forms of the corona. He found that all the coronal streamers which were shown in the photographs of the total eclipse of the Sun on April 16, 1893, at Mina Bronces, Chili, coincided with elliptical or parabolic curves having the Sun in one focus; in fact he was enabled to trace the separate streamers back to their centers of eruption, which could actually be recognized on the surface of the Sun. He believes it has been established by his investigations that the coronal streams are nothing else than streams of material ejected from the Sun and illuminated by its light. It is especially noteworthy (as he himself points out) that there is no indication in the form of these streamers of the resisting effect of a medium ; this is an admission which is all the more valuable from our point of view, since he himself seeks to explain the phenomena on the supposition of an extensive solar atmosphere. I thus regard it as confirmed by observation that these phenomena of a supposed solar atmosphere actually take place in free space. When we consider that our meteors, which certainly are compact masses, become luminous even at an altitude of over 100 miles, and that their velocity has been completely checked even at an altitude of many miles, we must recognize the impossibility of the supposition that the exceedingly tenuous matter of the corona passes undisturbed with such an enormous velocity along a path in an atmosphere of any description. The coronal streams require at least the same vacuous space as the comets, which have to pass through the same medium.

It is true that for some time the white prominences have been regarded by Tacchini as nebulous forms of dust-like constitution,

and a similar view with respect to the corona has been held, but by the investigation which forms the basis of this paper the origin of this dust-like matter is shown, and the assumption of free space instead of the previous one of an extensive solar atmosphere provides a free path for the outgoing coronal streamers.

The supposition that we see in the coronal streamers hydrogen diffused in the form of dust particles, finds an interesting confirmation in the observations of Schaeberle. He observes that the paths of these streamers at a great altitude are only partly visible, since even the one visible branch appears to extend only to a certain height, its completion above being absent. Our explanation of this fact is, that the hydrogen, or other gas, which is at first solidified by expansion, is heated as it travels along its orbit by the intense rays of the Sun, assumes a gaseous form, and thereupon becomes invisible. Let us consider the circumstances more closely. A path which reaches an altitude equal to that of the solar radius would require sixty-nine minutes for its ascent, the matter would therefore have to exist in dust-like condition, though exposed to the direct solar radiation, for about thirty minutes, if two-thirds of its path is to be seen.

The following table gives the numerical values which are required in order to apply this test to the explanation outlined above :

HEIGHT OF ASCENT (Radius of Sun = 1)	0.1	0.3	0.5	0.7	1.0	2.0
Initial velocity in kilometers per second	184.4	293.7	353.0	392.4	432.4	499.2
Duration of ascent	$12^m 53^s$	$25^m 43^s$	$37^m 33^s$	$49^m 33^s$	$69^m 0^s$	$3^h 8^m 19^s$

When we reflect that the ice crystals in our cirrus clouds remain quite unchanged in the Sun's rays, this explanation does not seem to be untenable.

Those streams which have already assumed a gaseous form, afford an explanation of what Janssen termed the photospheric reticulation, which Janssen himself has shown to be due to move-

ments of the solar atmosphere. The currents here discussed afford an explanation which is rendered somewhat more complete by the fact that the great variability of this reticulation within a period of one-half hour agrees closely with the time of descent which is here assumed.

In a precisely similar manner are explained the changes in the streamers of the corona itself; they naturally correspond with the time of ascent of our currents.

Finally, in the gaseous form of the returning currents we have an explanation of the fact that the spectroscope shows the lines of hydrogen, not only in the coronal streamers, but also in the intervals between them.

EXPLANATION OF FACULÆ.

The masses of hydrogen projected from the Sun into space with enormous velocity, being then under the influence of solar gravitation only, must naturally return by a straight or curved path to the surface. They will return to the surface with the same velocity with which they ascended, and must therefore strike the atmosphere like meteors. Even in the highest strata of the atmosphere they will consequently be raised to an enormous temperature, determined by the amount of arrested motion, which far surpasses the temperature of the other parts of the surface; since not only must the enormous heat of the gas lost by expansion be regained, but the enormous kinetic energy of the rapidly rising prominence must be converted into heat, and this is again further augmented by the heat which in the mean time has been gained from the rays of the Sun. That the portions of the surface thus highly heated must shine more brightly than the rest can hardly be called into question. Such brighter portions of the surface are well known as the faculæ. Their nature as revealed by observation agrees quite well with the supposition that they are nothing more than the places where the streams of gaseous meteors which surround the Sun strike its surface. When at a great height the streams will, it is true, spread out to some extent, but in the neighborhood of the surface they will

collide with the numerous oppositely directed streams, and will be deflected into paths which may give rise to those irregularly extended forms characteristic of the faculæ. The facts that they do not extend far beyond the Sun-spot zone, and are more numerous in the vicinity of Sun-spot groups may be explained thus : that there the eruptions, of which they are the consequence, have their origin.

I should here like to consider only two characteristic features of the faculæ, the very simple explanation of which, on the basis of the views here set forth, affords an excellent confirmation of the views themselves. As is well known, the faculæ are only visible to the observer when they are near the limb of the Sun. An explanation of this fact has heretofore been sought in the assumption that the faculæ are somewhat elevated portions of the photosphere, which, by the increasing absorption toward the limb lose less of their brillancy than the average surface. If the faculæ are those places where the gaseous meteors strike the Sun's surface, then their more elevated position is explained at the same time, not by the more elevated situation of the photosphere, which in fact cannot be detected by observations of the Sun's limb, but by the heaping up and intense incandescence of gas falling upon the Sun, for the effect here described must be produced even in the highest strata. This explanation is also strikingly confirmed by observation. Secchi wrote many years ago : "Lorsqu'une facule est au bord solaire tout au moins la chromosphère est plus vive et plus haute." I myself observed and remarked on the fact years ago.

This agreement of observations made without predisposition toward any special views is of great significance for the correctness of our theory. A small absorption must be the necessary consequence not only of these conditions, but also of the high temperature of the absorbing strata themselves. Since the faculæ in passing over the limb of the Sun indicate that the greatest height of the chromosphere is inconsiderable, we cannot ascribe a greater height to even the outermost portions of the solar atmosphere than that which the chromosphere attains. In

placing the upper limit of the atmosphere at so low a level we also solve the question why the hydrogen above the chromosphere so abruptly ceases to be luminous, for a solar atmosphere in static equilibrium could not possibly be so cold.

We do not wish to conceal from ourselves the fact that the long continuing or quiescent prominences present difficulties on the assumption of an empty space around the Sun, but it should be observed that the difficulty is not removed by the assumption of even a very tenuous high atmosphere, since, as was shown in the preceding investigation, the prominences in such an atmosphere must be in quite the same state of expansion as if they existed in free space. The solution must be sought elsewhere.

A second remarkable peculiarity of the faculæ is, that they show very brightly precisely those lines which are characteristic of the prominences, especially the H and K lines, so that Hale and Deslandres found it possible to photograph the faculæ at the center of the Sun's disk. When this fact was first discovered, M. Deslandres was inclined to regard the faculæ as the projected forms of prominences. This supposition is daily refuted by observation. That the faculæ nevertheless give the same lines is naturally explained by the fact that they are composed of identically the same gases which were elevated by the prominences, and which by again falling on the Sun become incandescent and give rise to the faculæ; the faculæ are identical, not with the rising prominences, but with their component substances falling back into the Sun, and therefore they show the same lines. Thus the glowing gaseous stratum assumed by Hale and Deslandres to exist above the faculæ, merely on the basis of their own observations, receives a confirmation and is quite naturally explained. According to this view no prominences will be found in the position of faculæ; but they may well be found near them, since the returning may give rise to outflowing streams. Hence it is that prominences are often seen by projection over faculæ on the limb of the Sun. This explains why the eruptive activity continues to be displayed for some time over the same group of faculæ.

These currents constantly rising and falling with such enormous velocities are the powerful convection currents which, in the form of prodigious movements, are alone capable of keeping up the enormous quantity of heat continually radiated by the surface of the Sun into outer space.

It only remains to note that my explanation of the faculæ is in the most satisfactory agreement with the theory of Sun-spots recently propounded by Egon von Oppolzer in an address before the Academy of Sciences of Vienna. Herr von Oppolzer's explanation requires a hot layer of gas above the spots. He assumes, not without foundation, that there must be places on the Sun where the atmosphere sinks, and by adiabatic compression acquires a much higher temperature than that of the corresponding level, in quite the same manner as shown by J. Hann with respect to the areas of high atmospheric pressure on the Earth. The explanation here given discloses the dynamic cause of this sinking motion on the Sun, and shows the origin of these highly heated strata; they are found everywhere above the faculæ, and in fact it is in the midst of the faculæ that the spots are known to be formed.

ON THE CAUSE OF THE DISPLACEMENT OF LINES IN THE SPECTRA OF THE PROMINENCES.

The gaseous meteors descending on the Sun afford a surprisingly simple explanation of the most remarkable of solar phenomena; namely, the displacement of the spectral lines. This phenomenon, remarkable alike for its rarity and its exceedingly sudden appearance and rapid disappearance, has hitherto been a prodigy to be wondered at by observers, but not explained. Perplexing in the highest degree has been its appearance at the foot of a prominence in the chromosphere, as well as in the center of the prominence itself at a high altitude. Even if the most tremendous forces are assumed to exist in the interior of the Sun, in order to explain the powerful eruption, it still remained inconceivable how forces could act within a gaseous body in a horizontal direction only, while the least resistance to internal

pressure is in an outward direction. Nevertheless, when such a rare phenomenon presents itself, the observer perceives a motion in the line of sight of 100^{km}-200^{km} per second develop along the limb of the Sun, at times over a range of 100000^{km} and in an interval of a quarter of an hour, and continue for many minutes, although a difference of height of only 1000^{km} offers a million times smaller pressure. An explanation of the phenomenon as the result of some kind of explosion is impossible for this reason. But if the assumption is nevertheless made that an explosion would produce enormous and persistent horizontal movements in spite of the inconsiderable upward resistance, then these horizontal movements must take place toward all sides alike, and therefore in opposite directions; displacements toward red and violet must therefore occur simultaneously. This is how-ever by no means the case; on the contrary, motion in only a single direction is usually observed.

This enigmatical appearance is easily and completely explained by the streams of gaseous meteors falling back upon the surface of the Sun. If such a stream should happen to fall upon a region of eruption, the two streams, both of which, according to observation, would generally have some inclination to the vertical, would unite to form resultant currents flowing in a generally horizontal direction.

The differences in direction, intensity and extent of the streams give the means of explaining the strangest peculiarities of these capricious phenomena. Above all, the possibility and usual occurrence of motion in one direction is completely explained, as well as the local character of such disturbances, and the rapid fluctuations of intensity at neighboring points, or even at the same point, so strikingly shown by the flame-like displacement forms which project from the spectral lines, and which indicate enormous velocities never directly observed in the ascent of the prominence. It is not impossible that the union of several favorably directed streams may give rise to a resultant current, the velocity along the axis of which may exceed that of any of the component streams.

Still more remarkable and as little explicable have always appeared to be the displacements of lines in the prominence itself, especially when they are localized at an enormous height. It sometimes happens that a motion of 100^{km}-200^{km} per second may be seen to arise in the course of a few minutes; the motion is confined to one small spot, the surrounding regions being quite unaffected. Occasionally the motion continues but a few minutes; at other times it may last more than half an hour. While it is highly problematical, on the one hand, that such enormous forces can suddenly spring into action at a height of many thousands of miles in the atmosphere, and that the motion to which they give rise can subside in the course of a few minutes, it is not less incomprehensible how such a motion can continue to be visible for the space of half an hour, for in this interval the moving masses would traverse a distance of 300000^{km}.

All these phenomena are easily and naturally explained with the aid of our streams of gaseous meteors. Thus, if a rapidly ascending prominence collides with a descending stream, a lateral component will be produced at the place of the collision, even at the greatest heights, which, if it happens to be directed in the line of sight, must give rise to a corresponding displacement of the spectral lines. Should the ascending masses cease to rise in the direction of the descending stream, the phenomenon would quickly come to an end—the matter diverted from its original course would be dispersed.

It is in this way only that the enormous motions can be explained, that I observed in the prominence of August 18, 1890. On that occasion a motion of 150^{km} per second was developed at a single place $40''$-$50''$ above the Sun's limb, and persisted for half an hour; at the same time a small cloud form or fragment at a height of $370''$ was receding from us with a velocity of 167^{km}, while the apparently adjacent fragments were not in the least affected.[1]

That this explanation assumes the collision of a powerful

[1] *C. R.*, iii, 562.

eruptive stream with an equally powerful descending stream—an occurrence which in itself would seem to be very improbable—only strengthens the views that we have adopted; for we are concerned with the explanation of a very unusual phenomenon, which evidently does not arise from causes that are in daily operation. The collision of such streams is however not so improbable as it might appear, since eruptions are not infrequent in the Sun-spot regions, and the ejected material must generally return to the same part of the surface.

HAYNALD OBSERVATORY,
Kalocsa, January 6, 1896.

FURTHER CONSIDERATIONS IN REGARD TO LAWS OF RADIATION.

By FRANK W. VERY.

A LARGE part of the earlier work on infra-red radiation having been done with apparatus constructed of rock-salt, and having been interpreted at first by the imperfectly known laws of refraction of this substance, it becomes necessary to review and amend some of the earlier conclusions. The recent determinations of the relation between dispersion and wave-length for rock-salt given by Rubens and confirmed by Paschen, being checked by measurements made with fluorite prisms, which are susceptible of greater accuracy than the deviations measured with rock-salt prisms, we must consider these latest results final, and conclude that the dispersion-curve for rock-salt is quite appreciably concave to the axis of wave-length for wave-lengths greater than 3^μ. I shall therefore adopt Rubens' constants, given on page 76 of THE ASTROPHYSICAL JOURNAL for January 1896, and Ketteler's formula (3) on page 72, noting that λ in the last term should have the exponent 2, and shall use these values as the basis of further transformations from dispersion to wave-length scale.

I will recall that for reasons given in his paper "Sur les spectres invisibles,"[1] Briot's formula was rejected by Langley, who adopted (for interpolation only) a hyperbolic rock-salt dispersion curve[2] which gave wave-lengths slightly longer than the longest observed by him in the spectrum of a rock-salt prism near $\lambda 5^\mu$, but otherwise agreed fairly with observation. Approximate wave-lengths greater than 5^μ were estimated by a tangent drawn to the curve.

The energy-curve for the normal spectrum of the carbon of an electric arc[3] was deduced by Langley and myself by a slightly

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[1] *Ann. Chim. et Phys.*, (6), **9**, 497, December 1886.

[2] Fig. 6, *loc. cit.*, and p. 503.

[3] *Am. J. Sci.*, (3), **40**, Plate 5, Fig. 2, August 1890. The curve there attributed to the

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different dispersion-curve, founded on the same values, but giving greater weight to the observations near 5$^\mu$, which, even in these earliest measures of wave-length, raise the suspicion of a reversal of curvature. Langley's determinations of wave-length in the rock-salt spectrum ended at λ 5$^\mu$.3, too near the point of inflection (at about 2$^\mu$.8) to make the existence of the reversal certain. Some variation in dispersive power exists with different specimens of rock-salt in the region between 1$^\mu$ and 2$^\mu$, as will be shown further on, but the adoption of Rubens' dispersion-curve will only diminish the wave-length of the normal maximum for the arc-carbon spectrum by about 0$^\mu$.06. In the extreme infra-red, however, the changes in the estimated wave-lengths are large. The uncertainty of measurements made with rock-salt prisms is enhanced by the peculiar properties of the substance. Its softness and liability to crack from sudden changes of temperature makes the working of accurate surfaces a task requiring both skill and watchfulness; and its hygroscopic property renders the preservation of these surfaces difficult. Different specimens of the substance probably vary in their dispersion, especially in that extreme infra-red region where, if at all, the absorbent properties of rock-salt for the longer waves are exerted; possibly also in the extreme ultra-violet; and certainly, though to a relatively limited extent, in the region where the dispersion-curve has its sharpest bend. The mode of formation of the substance by evaporation of sea water in seas or salt lakes without outlet, does not favor complete definiteness of composition; and a small amount of impurity, even if uniformly distributed, may affect the dispersive power to a measurable extent. I have, in fact, noticed appreciable variations in the deviation of light transmitted by successive small areas of the principal section of a rock-salt prism, otherwise uncommonly good. The mode of detecting these diversities is to set the cross-wires of the observing telescope upon a sharply defined Fraunhofer line, inserting, between the collimating lens and the prism, a movable diaphragm with

"electric arc," is, however, more accurately described as that of the spectrum of the incandescent carbon of the positive pole of the electric arc.

aperture about 0.001 that of the prism, the aperture being moved to and fro across the prism face until all parts are tested. The existence of locally distributed impurities, affecting the refractive power, is immediately indicated by a visible shifting of the Fraunhofer line as the diaphragm changes place. In very bad prisms this defect becomes so prominent that the spectral lines are hazy and almost invisible, until the offending parts of the prism have been cut out by a suitable templet. A variation of deviation, which is systematically connected with the distance of the transmitted pencil of rays from the refracting edge of the prism, is liable to be due to cylindrical prismatic surfaces, but this defect can be tested in other ways. Comparison of deviations in the spectra of two prisms made of material from different localities, namely, one of Baden rock-salt,[1] and the other a "Hastings'" rock-salt prism,[2] shows that the difference of deviation may progressively increase between K and Ω, from 0 to $+ 2'$.

Probably the most potent influence producing discrepancies in measures made with rock-salt prisms, is the very large variation of refraction with change of temperature. The feeble absorptive and radiative power of rock-salt causes it to change temperature slowly. It is therefore inadmissible to assume the temperature of a rock-salt prism from that of its enclosing walls or surrounding atmosphere, which may differ by many degrees if the temperature is changing rapidly. It is a good plan to take the temperature of a test-piece of rock-salt, similar to the prism and similarly placed, inserting the bulb of a thermometer in a cylindrical cavity drilled to the center of the test-piece, the bulb of the thermometer being surrounded by mercury, and its stem isolated and made tight by cotton wool. Reductions of observations made without this precaution are liable to be quite discordant, unless the temperature of the apparatus remains unusually constant. Comparisons of minimum deviations throughout the visible spec-

[1] S. P. LANGLEY, "The Solar and the Lunar Spectrum," *Mem. Nat. Acad. Sci.*, **4**, Appendix 2, Washington, 1887.

[2] S. P. LANGLEY, *Ann. Chim. et Phys.*, (6), **9**, 1886.

trum of two rock-salt prisms, with a range of temperature of over 30°C. between winter and summer, have shown a change of $-9''.5$ and $-9''.3$ respectively in the minimum deviation of a 60° prism for an increase of temperature of 1°C. within the given limits.

In view of these difficulties to which all measures made with rock-salt prisms are subject, and from the further analogy which, by Ketteler's hypothesis, leads us to expect that a substance so nearly transparent to infra-red radiations as rock-salt will have a dispersion in that region varying at a very moderate rate, I had been somewhat doubtful in regard to the magnitude of the curvature of the extreme infra-red branch of the dispersion-curve, and while employing the smaller wave-lengths indicated by Paschen,[1] had assumed a dispersion-curve so nearly rectilinear in the vicinity of $\lambda = 7^\mu$, that the maximum of a spectral energy-curve for $+40°$C. is scarcely changed by transformation to the wavelength scale. To this Dr. Paschen objects, and I willingly concede the point to him, remarking, however, that the adoption of Rubens' latest dispersion-curve will not materially affect the considerations which were advanced in my note of last November.

With these preliminary remarks I proceed to present anew some old observations, with the changes required to meet the recent advances in our knowledge of rock-salt dispersion, indicating the necessity of a further correction for atmospheric absorption which is not yet sufficiently appreciated, but which cannot be neglected if observations within the range of influence by the great water-band are to be used. New facts are also adduced which emphasiz: the variety to be expected in the radiative process.

From the prismatic spectral energy-curves published by Langley,[2] I have deduced normal curves for six temperatures by the aid of Rubens' dispersion curve. The transformation-factor in the first column of the following table is such as to give approx-

[1] *Wied. Ann.*, **53**, 337, 1894.

[2] *Ann. Chim. et Phys.*, (6) **9**, Fig. 4, 1886; and *Mem. Nat. Acad. Sci.*, **4**, Part 2, Plates 5 and 10, Washington, 1887.

imate equality of length between $0^{\mu}.4$ and $9^{\mu}.6$, when the areas of the energy-curves are equal on the normal and prismatic scales. For the n and λ curve for rock-salt we have:

$$n^2 = a^2 + M_2 (\lambda^2 - \lambda_2^2)^{-1} - k \lambda^2;$$

differentiating, we get:

$$\frac{dn}{d\lambda} = -\frac{\lambda}{n} \left\{ \frac{M_2}{(\lambda^2 - \lambda_2^2)^2} + k \right\}.$$

If the relation between minimum deviation (D) and wavelength (λ) is desired, we must substitute for a $60°$ prism

$$n = 2 \sin \left(\frac{D}{2} + 30° \right),$$

whence

$$\frac{dD}{d\lambda} = - \frac{\lambda}{2 \sin \left(\dfrac{D}{2} + 30° \right) \cos \left(\dfrac{D}{2} + 30° \right)} \left\{ \frac{M_2}{(\lambda^2 - \lambda_2^2)^2} + k \right\} = \tan \phi.$$

The transformation-factor adopted here is $\tan \phi \times 86.5$.

The value of the normal maximum for the temperature $+40°$ C. is $7^{\mu}.54$, a little larger than the number $(7^{\mu}.3)$ given in my former note. The maximum is in this case far enough away from the great water-vapor band to be unaffected by its presence, especially since the air at the time of the measurements was very cold and dry; but owing to the smallness of the excess, the maximum would be considerably displaced if a comparison-screen at absolute zero were to be substituted for the actual screen at $-6°$ C. I estimate that such a substitution would increase the wave-length of the apparent maximum about $0^{\mu}.5$, which would make the corrected value $\lambda_{max.} = 8^{\mu}.04$. The positions of the normal maxima for the hotter bodies would not be appreciably changed by the adoption of an absolutely cold comparison-screen; but a glance at the values of the normal maxima will show the necessity of a further correction for the influence of the great water-vapor absorption band between 5^{μ} and 7^{μ}. The maximum for $815°$ C. is too far from the great band to be affected; but at temperatures above $300°$ C. and below $800°$ C., the normal maximum being of shorter wave-length than the band, the wave-length of the apparent maximum is too small, while it is too

large at temperatures below 200° C., because the band is here on the opposite side of the maximum. Assuming that the normal maxima for the extreme temperatures have not been altered by this cause, I adopt such a curve as will distribute the errors between these points, obtaining thus the final corrected $\lambda_{max.}$, and the product $\lambda_{max.} \times T$ indicated by Paschen's law, as well as $\lambda_{max.} \times \sqrt{T}$ required by Michelson's law.

The oxidized copper in the following measures had been thickly coated with lampblack, but the lampblack had probably mostly burned off at the highest temperature, except perhaps where protected in the surface pores.

SPECTRAL ENERGY-CURVES.

Reduction by Rubens' dispersion-curve			815° C., 1088° Abs.		525° C. 798° Abs.		330° C. 603° Abs.		178° C. 451° Abs.		119° C. 392° Abs.		40° C. 313° Abs.	
Transformation Factor	Rock-salt Min. Deviation	Wave-length	Prismatic ordinate	Normal Ordinate	Prismatic Ordinate	Normal Ordinate	Prismatic Ordinate	Normal Ordinate	Prismatic Ordinate	Normal Ordinate	Prismatic Ordinate	Normal Ordinate	Prismatic Ordinate	Normal Ordinate
0.398	39°30'	1μ.93	960	382	620	247	350	139	...	...	...	...	....	....
0.302	39 20	2 .67	3220	972	1440	435	960	290	263	79	...	...	....	....
0.323	39 10	3 .53	5800	1873	3510	1134	1760	569	312	101	...	...	....	....
0.366	39 00	4 .28	5230	1914	3310	1211	1900	705	375	137	145	53	....	....
0.410	38 50	4 .93	4450	1825	2780	1140	1580	648	413	169	165	68	....	....
0.452	38 40	5 .50	3750	1695	2310	1044	1260	570	426	193	178	80	....	....
0.493	38 30	6 .03	3090	1523	1880	927	1000	493	424	209	185	91	31	15.3
0.531	38 20	6 .52	2550	1354	1540	818	770	409	415	220	184	98	34.5	18.3
0.567	38 10	6 .99	2060	1168	1270	720	610	346	399	226	179	102	37.5	21.3
0.600	38 00	7 .42	1680	1008	1040	624	460	276	375	225	172	103	38	22.8
0.632	37 50	7 .83	....	....	....	....	....	...	344	217	163	103	35.5	22.4
0.663	37 40	8 .22	....	....	....	....	....	...	316	210	152	101	32	21.2
0.692	37 30	8 .59	....	....	....	....	....	...	290	201	141	98	29	20.0

Absolute Temperature T	Prismatic Maximum	Normal Maximum	Corrected $\lambda_{max.}$	$\lambda_{max.} \times T$	$\lambda_{max.} \times \sqrt{T}$
1088°	39°10'	3μ.96	3μ.96	4308	130.6
798	39 06	4 .05	4 .55	3631	128.5
603	39 02	4 .24	5 .24	3160	128.7
451	38 37	7 .16	6 .20	2796	131.7
392	38 27	7 .60	6 .80	2666	134.6
313	38 02	[8 .04]	8 .04	2517	142.2

In the reduction of these measures which Rubens has given,[1] the spectral energy-curves have not been redrawn on the normal scale. As corrected here for water-vapor absorption, it will be seen from the last two columns of the previous table that the wave-lengths of the normal maximum ordinates follow Michelson's law more closely than Paschen's. The products $(\lambda_{max.} \times T)$
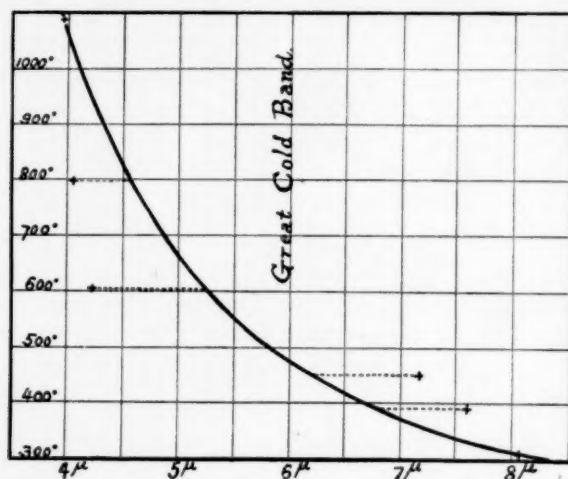
Curve showing probable position of maximum in a normal spectral energy-curve, if undisplaced by the absorption of the great water-vapor band. Radiating surface = lampblack. Abscissas $= \lambda_{max.}$ Ordinates = absolute temperature.

are by no means constant. Paschen's law is therefore only applicable to the body (iron oxide) from which it was obtained.

An extension of the lampblack curve to the position of the normal maximum for the electric arc carbon gives a value of $(\lambda_{max.} \times T)$ twice as great as that observed, indicating that lampblack approaches the ideal absolutely black body more closely than graphite. It is evident that no reliable estimate of the solar temperature can be obtained from these curves without a knowledge of the selective radiating power of the solar photosphere.

Differences in selective radiating power may be so great as to entirely alter the form of an energy-curve, as is well shown in

[1] *Wied. Ann.* **53**, 267, 1894.

the following comparison of the spectral energy-curves of an Argand and a Welsbach burner, the total radiation being approximately equal:

Wave-length	μ 0 .50	μ 0 .60	μ 0 .72	μ 0 .98	μ 1 .44	μ 1 .93	μ 4 .28	μ 7 .42	μ 9 .60
$\dfrac{\text{Welsbach}}{\text{Argand}}$ } Ratio	2.000	0.971	0.530	0.566	0.735	0.791	1.042	1.909	1.777

Here the maximum energy has the greater wave-length in the Welsbach curve (rock-salt prismatic maximum of Welsbach $=39°$ $15'$, of Argand $=39°$ $28'$), although the incandescent mantle cannot differ greatly from the temperature of the radiating carbon particles of the Argand flame. With the same consumption of gas, the Welsbach burner radiates much more powerfully than the Argand burner,[1] and loses a smaller proportion of its heat by convection, owing to the impeding of the hot gaseous circulation by the friction of the fine meshes of the mantle. The figures given above do not fully express the great superiority of the Welsbach over the Argand burner as an illuminant. With equal flow of gas (3.6 cu. ft. per hour), the static

[1] The open-meshed mantle of the Welsbach burner occupies only a fraction of the flame section, but so also do the scattered particles of incandescent carbon in the Argand flame. Not knowing the relative fractional sections occupied by the incandescent material, we can only say that the process is something like this : We may suppose that the intrinsic radiating power of Welsbach material is somewhat less than that of carbon. Then, if the fractional sections occupied by the Welsbach mesh and by the swarm of carbon particles are equal, the Welsbach material must be hotter for equal radiation, and still hotter for a radiation thrice as great, while it could only have the same temperature if its fractional section were correspondingly larger. But in view of the partial transparency of luminous flames, it is not probable that the carbon particles occupy more of the section than the Welsbach mesh. We may conclude, then, that the Welsbach mantle is not necessarily hotter than the carbon particles, in spite of the greater extent of its spectrum toward the short wave-lengths; but there can be no doubt that the Welsbach flame, area for area, disperses more energy in the form of radiation than does the Argand. Arguing from the ordinary analogies, the greater extension of the Welsbach spectral energy-curve towards the short wave-lengths would indicate that the Welsbach source is the hotter, but the longer wave-length of its maximum that it is the colder, while the fact that the radiation of both sources is supplied by the consumption of equal amounts of an identical gas would favor a substantial equality of temperatures. Probably the third alternative is correct.

pressure being 3.5 inches of water, and the flow-pressure 2.5 inches, the candle-power of the Welsbach light was 3.18 times that of the Argand, the Welsbach light having nearly 3 times the intensity of the Argand in the orange of the spectrum and 6 times the Argand intensity in the blue as determined by measures with a spectrophotometer. The heat lost by radiation was:

3065 small calories per minute from the Welsbach.
1086 small calories per minute from the Argand.

while a rough estimate of the convection losses gave:

8000 small calories per minute from the Welsbach.
10000 small calories per minute from the Argand.

The above is a striking illustration, but by no means an extreme case, of the difference in the selective radiating power of different substances, and in addition to this we have frequently considerable changes in the selective radiating power of the same substance at different temperatures.

The original measurements in the spectrum of the positive carbon of the electric arc given by Langley,[1] were for comparison with solar measurements made with the same arrangement of apparatus, and for this purpose require no correction for the impurity of the spectrum, since both spectra are affected alike; but in transformation to the normal scale where the true form of the spectral energy-curve is required, a correction for the impurity of the spectrum is necessary, and has been applied in the reduction already cited.[2] From the smooth curve which represents the original measures very closely, the following normal values have been taken:

λ	μ 0.6	μ 0.8	μ 1.0	μ 1.2	μ 1.4	μ 1.6	μ 1.8	μ 2.0
Energy.....	270	420	500	510	493	440	362	296

The maximum is at $1^{\mu}.16$, or $1^{\mu}.10$ by Rubens' dispersion-curve. It would be forcing the observations unjustifiably to make the position of the maximum less than $1^{\mu}.1$.

[1] *Am. Jour. Sci.*, (3), **38**, 438, December 1889.
[2] *Am. Jour. Sci.*, (3), **40**, Plate V., Fig. 2, August 1890.

It is true that the energy-curve for the spectrum of the positive arc-carbon is only a first approximation, and that a very large number of similar curves must be summarized in order to get one ideally accurate; but it does not seem necessary to wait for this. The results already published are not likely to be grossly erroneous. Some irregularity in the arc-carbon radiation must be expected, since the arc is never still for very long at a time. In this kind of observation nothing will take the place of continuous human supervision, and in Langley's work one assistant was detailed to keep the hottest part of the incandescent carbon centered in respect to the spectroscope slit and axis of collimation; but it is evident that when the arc leaps to the opposite edge of the crater, it must take some seconds before this part can become as hot as that previously in view, even if the adjustment of position is made instaneously; and thus irregularities are produced in the spectral energy-curve which are fortuitous, and which have to be removed by drawing a smoothing curve. While, however, there must be variations of temperature produced by arc-fluctuation, the explanation of electric arc-phenomena recently given by Professor S. P. Thompson in his Cantor lecture before the London Society of Arts,[1] which supposes that the solid carbon is covered by a thin layer of melted carbon continually vaporizing, or even in a state of active ebullition in the case of a hissing arc, suggests that on the whole the variations of intrinsic radiating power cannot be excessive, if the surface in the vicinity of the issuing arc is kept near the constant temperature of a liquid boiling point.

Dr. Paschen, from his hypothesis in regard to the wave-length of maximum radiation,[2] computes the temperature of the positive carbon in the arc at 2729° Abs., but direct observation must take precedence. Wilson and Gray, cited in my previous note, found the temperature of the positive carbon 3600° Abs. or 3300° C. Their method founded on the use of Joly's expansion thermoscope, is perhaps open to criticism; but the

[1] Reported in London *Industries and Iron*, November 1, 1895, and in later numbers of *The Electrician*.

[2] ASTROPHYSICAL JOURNAL, **3**, 153, February 1896.

latest result of Violle, 3600° C. or 3900° Abs., is so thoroughly guarded, and made moreover by one whose skill as an experimenter is of the highest order, that it deserves exceptional weight.

In 1892 Violle,[1] working with an arc produced under very varied conditions, the consumption of power varying from 500 to 34000 watts, found that the intrinsic brilliancy of the positive crater is identically the same for arcs of these different powers. This had also been observed by Rosetti and by Abney, though for a much smaller range. This constancy suggests as a cause one or the other of the two chief means by which uniform temperature can be maintained in the midst of surrounding thermal change. Either the carbon is at its melting point or its boiling point, unless possibly these two points coincide, carbon having no intermediate liquid state. If Professor Thompson's suggestion is accepted, we may suppose the liquid layer to exist, but to be so thin that it escapes detection except through the bumping of its explosive boiling. The fact, however it is to be explained, assures us that the temperature of the electric arc carbon does not vary through more than a very slight range. Having settled this point, Violle proceeded to determine the temperature of the incandescent carbon by knocking off fragments of the hot tip into a calorimeter, protected by asbestos screens, and corrected by blank experiments executed before and after the measurement. The result would therefore be a minimum (there being a slight loss of heat in the fall of the piece) were it not that it was necessary to use a theoretical value of the specific heat of carbon in the reduction which gave the temperature of the positive carbon 3500° C. This defect Violle subsequently remedied,[2] finding that:

" 1. Above 1000° the mean specific heat of graphite increases linearly with the temperature according to the formula $C_o^t = 0.355 + 0.00006\ t$.

" 2. The heat given up by 1 gram of solid graphite between its temperature of volatilization and 0° is 2050 calories.

[1] *C. R.*, **115**, 1273, 1892.   [2] *C. R.*, **120**, 868, 1895.

" 3. Consequently the temperature of ebullition of carbon is 3600°."

The experiments of Dr. Louis Duncan[1] show that the electromotive force, necessary to vaporize carbon, increases with the atmospheric pressure. At 1 atmosphere the fall of potential at the positive pole is 39 volts, as Professor S. P. Thompson had previously shown, but at 10 atmospheres the fall is 48 volts. The boiling point of carbon therefore probably rises with the pressure, and at such pressures as Jewell finds at the solar photosphere, the temperature of condensation of carbon mist must be very much higher than 3600° C.[2]

In another article by Violle[3] it is shown that while the temperatures of the carbons remain constant, they being cooled by evaporation, the arc itself is, in general, hotter than the carbons and grows hotter with increase of current. But I pass this by, as we are here dealing with the spectra of solid bodies. It seems to me, however, that ample evidence has been adduced, proving that the temperature of the positive electric arc-carbon cannot be less than 3900° Abs. for which $\lambda_{max}. \times T = 1.10 \times 3900 = 4290$, and that Paschen's law of radiation completely breaks down at high temperatures, while it can only be allowed as an approximation at low temperatures for a particular substance which does not fulfil the ideal of an absolutely black body so well as lampblack, for which a different law is indicated. Owing to causes some of which have been described in this article, in the present state of infra-red measurement, discrepancies in the value of supposed "constants" which would be intolerable in more exact branches of physics, are less of a reproach than it is to be hoped they may eventually become.

[1] London *Electrician*, **31**, 360, 1893.

[2] The experiments of W. E. Wilson (*Ap. J.*, **2**, 212, October 1895) at first sight appear to prove the opposite of this, but are really inconclusive. It is probable that the electric power was insufficient to maintain the arc at high pressures, for it is hardly possible that the presence of an atmosphere of nitrogen should totally change the physical properties of the arc. A crucial test would be to find whether the temperature of the positive carbon (kept always at the maximum temperature obtainable with unlimited electric power) does or does not rise with increasing pressure.

[3] *C. R.*, **119**, 949, 1894.

THE SPECTROSCOPE OF THE EMERSON McMILLIN OBSERVATORY.

By H. C. Lord.

DURING the winter of 1895, Mr. Emerson McMillin wrote to the Board of Trustees of the Ohio State University offering to build and equip an observatory. Plans for a building were at at once prepared by Professor Bradford, and a site chosen, well to the northwest of Columbus, which is almost entirely free in clear weather from the smoke of the city. A committee was appointed to select the apparatus and, as a member of the committee, the writer was sent East to visit several observatories and instrument-makers. In equipping this institution, two considerations were to be met : first, an opportunity should be offered to the students of the state for thorough elementary as well as advanced instruction in Astronomy ; second, it should be prepared to take up at least one line of astronomical investigation and carry it out successfully. In consideration of the above facts, it was deemed wise to purchase a combined transit and zenith telescope, chronograph, chronometers, sextants, etc., for instruction, but to devote the bulk of our money to an equatorial of as large aperture as possible, provided with a powerful spectroscope having a wide range of dispersion. The equatorial is of 12½ inches clear aperture with objective by Brashear and mounting by Warner and Swasey. This mounting is too well known to need description. It is simple, elegant, massive in design, and accurate in workmanship. No attempt has been made to cumber it with the so-called conveniences sometimes applied to modern telescopes, but everything that is necessary is on the instrument and in exactly the place that it should be. The objective is of the new form made by Mr. Brashear, and has given most excellent satisfaction.

The spectroscope is shown attached to the telescope in Plates II. and III. A brass ring bolted to the tube holds, by means

of a bayonet joint, a heavy hollow cylinder of brass. The lower end of this carries a position circle graduated to degrees. Over this cylinder fits a jacket, which can be turned through 360° about the axis of collimation and clamped in any position. In this are fastened two thin steel tubes, about 46^{mm} in diameter, carrying the spectroscope proper. The general design of this instrument is a sort of combination of the star spectroscope of the Lick and Potsdam observatories. A light but very rigid framework, built up of sheet brass, and clamped by four split hinged rings to the rods from the jacket, carries the collimator. This can be moved along the axis of the telescope by a rack and pinion, clamped, and its position read on a scale graduated to millimeters. To the lower end of this framework is attached a counterbalanced arm to carry the observing telescope or camera. This arm is also built of sheet brass and is hinged at two points, as is done on the Lick spectroscope. The angle of deviation is given by a circle 200^{mm} in diameter re ding to thirty seconds of arc. The prism table is similar to that of the Lick spectroscope, except that it is on the same side of the instrument as the graduated circle, and carries an arm ending in a vernier also reading to thirty seconds of arc. Behind the slit-plate is a diagonal eyepiece for viewing the star from behind the slit. The jaws open symmetrically, the amount being measured by a graduated head reading to the $\frac{1}{800}$ of an inch. The comparison apparatus and cylindrical lens (which is attached to the spectroscope as arranged for the grating for the sake of illustration) are well shown in the figure. The instrument thus far described is arranged to carry either a grating, 60° dense prism or a 60° light prism.

At my request Mr. Brashear designed and built the attachment shown in Plate III. This consists of a brass box, provided with two dense 60° prisms automatically kept at the angle of minimum deviation, into which either the observing telescope or the camera can be screwed. Two brace rods run from these tubes to the body of the spectroscope, clamping them rigidly in place. A diagonal eyepiece is used to observe the image of

the star and slit from the front face of the first prism, as is done at Potsdam. The instrument is provided with a double set of objectives, one for the visual and one for the photographic portion of the spectrum. Diaphragms are provided whereby the ratio of focal length to aperture can be kept the same as in the great objective of the equatorial. As to the ease with which this instrument can be attached to the telescope, it is sufficient to say that one man can remove the micrometer and replace it by the spectroscope in less than sixteen minutes, while the change from the battery of two prisms to the single prism can be made in five minutes.

I give below a few of the dimensions of the instrument:

Clear aperture of objectives - - - -	44^{mm}
Focal length of objectives about - - -	380^{mm}
Ruled portion of grating is - - - -	$35^{mm} \times 46^{mm}$
No. lines to inch of grating - - - -	14438
The dense prism is - - -	$60^{mm} \times 40^{mm}$ on its face
The light prism is - -	$70^{mm} \times 50^{mm}$ on its face
The prisms of the battery are -	$56^{mn} \times 38^{mm}$ on their faces.

Linear dispersion on photographic plate from F to midway between H and K when G is in minimum deviation is as follows:

For light prism - - - -	$13^{mm}.1$
For dense prism - - - - -	$21^{mm}.3$
For battery of two prisms - -	$43^{mm}.1$

The following scales are provided, all graduated in the same way and all reading to millimeters, except that for slit-width: for focus of collimator, observing telescope, camera, cylindrical lens, position of slit with respect to the great telescope, and the circle which gives the position of the observing telescope and prism.

Of the optical qualities of this instrument it is needless to speak; the definition is simply superb and the mechanical construction leaves almost nothing to be desired.

In connection with the spectroscope, the observatory possesses an excellent comparator by Carl Zeiss. This is provided with two micrometer microscopes reading to thousandths of a milli-
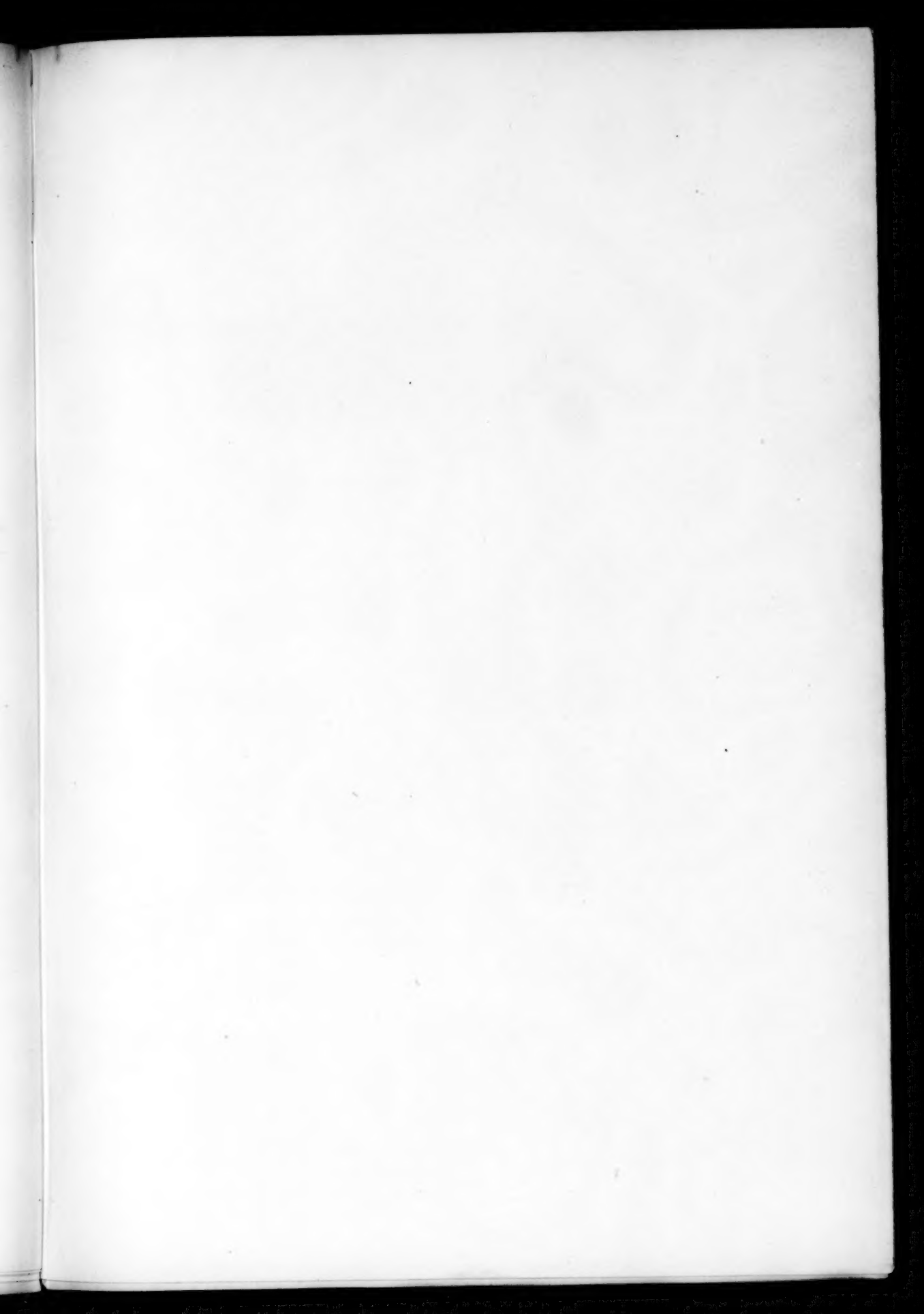
PLATE II.
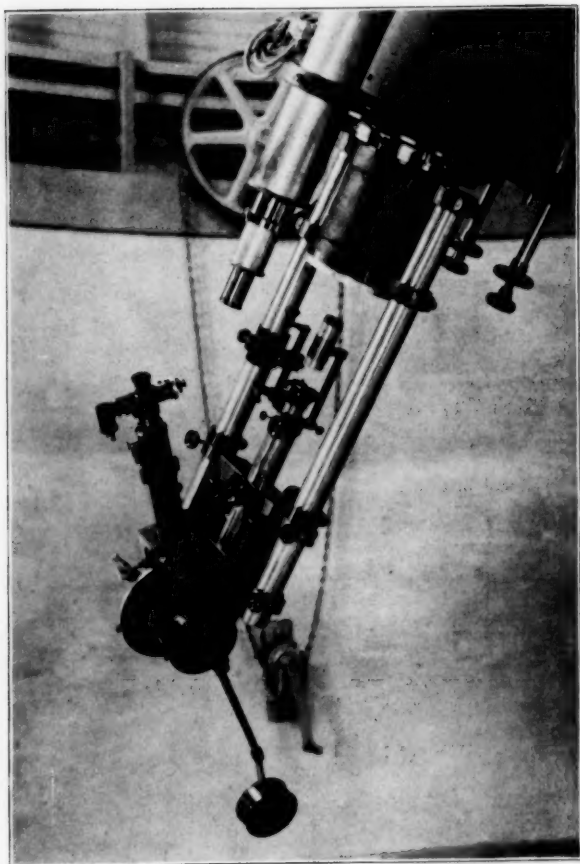
THE SPECTROSCOPE OF THE EMERSON McMILLIN
OBSERVATORY.

PLATE III.
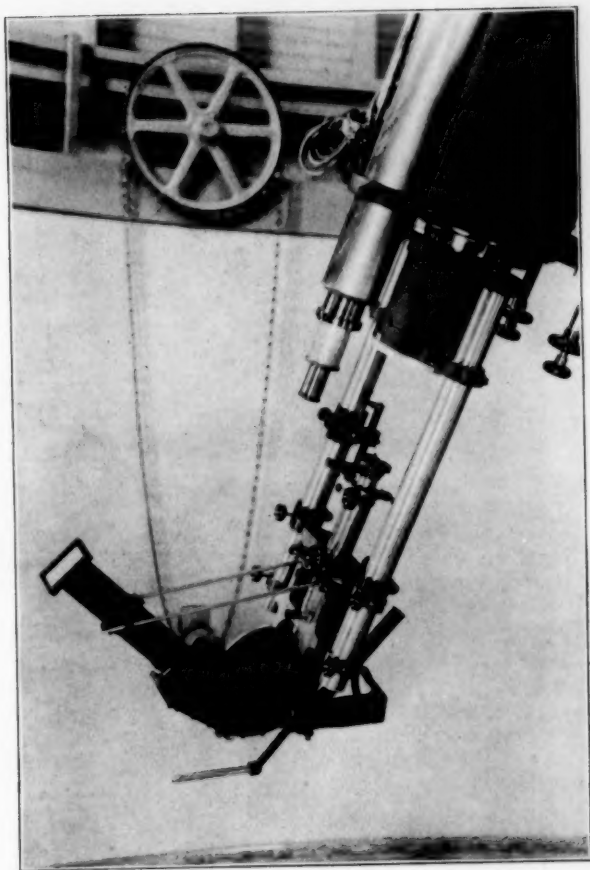
THE SPECTROSCOPE OF THE EMERSON McMILLIN
OBSERVATORY.

meter.   One has a rack and pinion movement for focussing on the photographic plates; the other is fixed over a scale 100^{mm} long, graduated to fifths of a millimeter.   The divisions are the finest I have ever seen; their errors have not yet been investigated, but the work will be begun at an early date.

The building is shown in the Frontispiece.   It is built of gray pressed brick, rock-faced in the second story, and contains an office, library, class room, clock room, dome, dark room, transit house, hall way, two closets and a large basement.

The entire carpenter work was made by our college carpenter, Mr. Woodruff, and the patterns for the dome mechanism by the students of the university.   Thus far everything has given entire satisfaction.

THE MODERN SPECTROSCOPE. XIX.

THE OBJECTIVE SPECTROSCOPE.

By GEORGE E. HALE and F. L. O. WADSWORTH.

LIKE most forms of spectroscopic apparatus in use at the present time, the objective prism is due to Fraunhofer. In his first attempts to observe the spectra of stars he employed a prism of 60° angle, supported in front of a theodolite objective of 3^{cm} aperture. Subsequently he used a prism of 37° 40' angle with a comet-seeker of 10^{cm} aperture, a cylindrical lens being held before the eye for the purpose of broadening the spectra. With this apparatus Fraunhofer observed the characteristic features of the principal types of stellar spectra, and measured with a micrometer the positions of the more important lines.[1]

In 1838 Lamont repeated these observations with the original apparatus of Fraunhofer, but without adding anything to the earlier results. Secchi observed the spectrum of Sirius with a theodolite and objective prism in 1855, but his extensive investigations of stellar spectra were not commenced until 1862, when he employed for his earlier observations a direct-vision pocket spectroscope attached to the Merz refractor of the Collegio Romano. Having exhausted the capabilities of these and other direct-vision spectroscopes, and desiring to push his investigations still further, he applied a prism $16^{cm}.2$ in diameter, of 12° refracting angle, to the nine-inch refractor of the observatory. With this apparatus the D and b lines in the spectrum of Aldebaran were separated by a distance of 315″, and the D lines and many groups of iron lines between b and E were resolved. The spectrum of α Lyrae required two minutes to transit across a fixed cross-hair, and Secchi suggested that the relative positions of the lines could be determined by noting their time of transit. That part of the objective which was outside the circular prism was

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[1] *Denkschriften d. K. Akad. d. W. München,* **5,** 1817.

covered except in two places. At one of these points a circular hole
was left, so that a star could be observed directly; at the other
was placed an achromatic prism giving a deviation of the image
equal to that of the objective prism, so that a colorless image
of a star could be observed at the same time with its spectrum.[1]
This device did not give satisfactory results, and it was replaced
by Fraunhofer's arrangement of a finder fixed with its axis
inclined to the axis of the equatorial at an angle equal to the
deviation of the prism. Both of these arrangements were used
not only for the purpose of setting the equatorial upon the star,
but also to give points of reference in measuring the positions
of the spectral lines.[2]

Respighi early adopted the objective prism for his investiga-
tions of stellar spectra, and in 1871 both he and Lockyer used
objective spectroscopes for observing the spectrum of the corona
during the total eclipse. Prismatic cameras have also been used
with success at the eclipses of 1882, 1886 and 1892. In 1885 Pro-
fessor Edward C. Pickering adopted the objective prism for the
extensive researches on stellar spectra established in that year at
the Harvard College Observatory in memory of Dr. Henry Draper.
Photography was used for the first time in recording stellar
spectra with an objective prism, and the results far surpassed
those of the earlier visual observations. In the course of this
work prisms of small angle (from 5° to 13°) and of 8, 12 and 24
inches aperture, have been employed in photographing most of
the stars within their reach in the northern and southern skies.[3]
During the last few years Professor J. Norman Lockyer has used
an objective prism of 6 inches aperture and 45° refracting angle in
his photographic studies of stellar spectra at South Kensington.
At Herèny, Hungary, Herr Eugen von Gothard has made excel-
lent photographs of the spectra of the stars and planetary nebulæ
with an objective prism of ten inches aperture, attached to a
reflecting telescope.[4]

[1] SECCHI, *Le Stelle*, p. 80. [3] *A. and A.*, **11**, 199, 1892.

[2] *Ibid.*, p. 84. [4] *A. and A.*, **12**, 51, 1893.

Theory of the Objective Spectroscope.

As has already been pointed out in previous papers, the three questions which most concern us in considering any form of spectroscope are the resolving power, the brightness of the spectrum, and the practical visual and photographic purity of the spectrum. As a basis of comparison we will assume, as in the general discussion of the astronomical spectroscope, a constant resolving power r. For the objective spectroscope it is only necessary to consider the case of stellar spectra, and these may be divided into two classes: bright line spectra, and continuous spectra.

As regards brightness, it is generally admitted that the objective spectroscope has a great advantage over every other form of instrument of the same resolving power. This advantage is due to two distinct causes: (1) the greater simplicity of this form of instrument and the correspondingly less loss of light by reflection and absorption.[1] (2) The concentration of all the light from the source (save the loss by reflection and absorption just noted) in the spectral image.

In the case of the compound spectroscope, only a part of the light from the star image can pass through the slit, even when the optical definition and achromatism is perfect (as is never the case with refractors) on account of the finite width of the diffraction pattern. If the achromatism were perfect, the image steady and the slit width just equal to the diameter of the second dark ring, about nine-tenths of the total light from the star image would be transmitted.[2] In general, on account of the diminution of purity with increase in slit width, we cannot admit of a slit width more than one-half as great as this, or about equal to the diameter of the *first* dark ring; and under these conditions over

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[1] If the resolving power is constant the loss by absorption in the prism train (if a prism train is used) will be the same for all forms of instrument which employ simple prisms; but there will be an increased absorption in the compound spectroscope by reason of the two additional lenses. The loss by reflection in the compound spectroscope will be much greater, not only on account of the larger number of optical surfaces involved, but also on account of the larger angle of the prisms employed. There will also be considerable loss by reflection from the edges of the slit, etc.

[2] *Phil. Mag.*, March 1881.

16 per cent. of the light is lost, or more than is lost by reflection from the faces of a single 60° prism.

In the case of the refractor there is a further loss for all but one particular region of the spectrum, by reason of the want of achromatism and the consequent enlargement of the diffraction image for those wave-lengths which are out of focus. There is also an important loss in the intensity of the spectral image of bright line spectra, due to the further broadening of the slit image by the diffraction of the observing telescope.

Taking into account all of these losses, and supposing the slit width equal to the diameter of the first diffraction ring, as above, we obtain for the intensity of the spectral image in the case of the compound spectroscope[1]

$$i \cong \frac{1}{3} k e \frac{\beta^2 A^2}{r \lambda (\lambda_1 - \lambda_2)} \quad \text{for continuous spectra;} \qquad (1)$$

and $\quad i = \frac{1}{4} k e \frac{\beta^2 A^2}{\lambda (2\lambda + \frac{1}{4} r \Delta \lambda)} *$ for bright line spectra; $\qquad (2)$

where k is a constant whose value depends on the apparent intensity of the star, *i. e.*, on its absolute intensity k_0 and its angular magnitude ω, or,

$$k = k_0 \omega^2.$$

These formulæ are deduced on the assumption that the slit width is equal to the theoretical diameter of the first diffraction ring, but that the star image is uniformly bright across the whole width of the slit, which will be the case when the tremor disk due to aberration is about twice the theoretical diameter of the central diffraction image. If we assume theoretically perfect conditions, which will be convenient in comparing the brightness of the spectra formed by the objective spectroscope with those obtained by a compound spectroscope under the very

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[1] See *Ap. J.* **1**, 52, 1895.

* In deducing this formula in a previous paper, the assumption was made that the effective broadening due to diffraction and dispersion was one-half the total broadening. Since then it has been found that the factor is more nearly one-third than one-half. The only change which this introduces in the expression for i is in the coefficient of $r \Delta \lambda$, which becomes one-quarter instead of one-third as given in previous papers.

best conditions, the coefficients in the above formula will be slightly changed. For we have, using the same notation as above:
For the equivalent effective width of slit in case of compound spectroscope $\cong \frac{1}{2} s \cong \frac{\lambda}{\psi}$; and for the average intensity of star image $k_0 \omega^2 \frac{A^2}{(\omega A + \lambda)^2} \psi^2 \cong k \frac{A^2}{\lambda^2} \psi^2$;

$$\therefore i = \frac{2}{3} k \epsilon \beta^2 A^2 \frac{1}{r \lambda (\lambda_1 - \lambda_2)} \quad \text{for continuous spectra;} \quad (3)$$

and $$i = \frac{4}{5} k \epsilon \beta^2 A^2 \frac{1}{\lambda (2\lambda + \frac{2}{3} r \Delta \lambda)} \quad \text{for bright line spectra.}[1] \quad (4)$$

In the corresponding case of the objective spectroscope we evidently have for the intensity of the spectral image of a star

$$i' = k_0 \gamma^2 \frac{S^2}{\left(\dfrac{\omega A + \lambda}{\beta}\right) \left[\dfrac{\omega A + \frac{1}{2}(2\lambda + r \Delta \lambda)}{\beta}\right]} \quad (5)$$

where γ is the angular magnitude of the telescope objective as viewed from the star, and S the linear magnitude of the star.

Hence $$i' = k \epsilon' A^2 \beta^2 \frac{1}{r \lambda (\lambda_1 - \lambda_2)} \quad \text{for continuous spectra,} \quad (6)$$

and $$i' = m k \epsilon' A^2 \beta^2 \frac{1}{\lambda (2\lambda + r \Delta \lambda)} \quad \text{for bright line spectra.} \quad (7)$$

In the last formula, the constant m varies from $m = 2$ for small values of $r \Delta \lambda$—for which the effective broadening in the direction of the length of the spectrum is nearly one-half the total broadening—to $m = 3$ for large values for which the effective broadening is more nearly one-third the total. As a mean value m may be taken to be two and one-half.

In case the diffraction image is broadened by aberration due to atmospheric irregularities, etc., the intensity of the spectrum is diminished. For continuous spectra this diminution is simply proportional to the increased broadening of the spectrum (since the length of the spectrum is only inappreciably increased). Hence for the case assumed for (1) (in which the broadening by aberration is about equal to that caused by diffraction), the inten

[1] See preceding footnote.

sity of spectrum for the objective spectroscope would be diminished by about one-third

or
$$i' \cong \frac{1}{2} k \epsilon' A^2 \beta^2 \frac{1}{r\lambda (\lambda_1 - \lambda_2)}. \tag{8}$$

For bright line spectra the intensity would be diminished more, since both the width and height of the line are increased. To find the effect we must add to both terms in the denominator of (5) a term of the form

$$\frac{\kappa}{\beta} = \frac{\kappa}{A} F *$$

where κ is a constant depending upon the amount of aberration, *i. e.*, on the disturbances in the atmosphere.

We then obtain for i

$$i = k \epsilon' A^2 \beta^2 \frac{1}{\left[\omega A + \frac{1}{2}(2\lambda + \kappa) \right] \left[\omega A + \frac{1}{2}(2\lambda + r\Delta\lambda + \kappa) \right]}. \tag{9}$$

If we assume as before that the term κ is equal to 2λ, *i. e.*, that the total broadening is twice that due to diffraction alone, and neglect ωA as very small in comparison with the other terms, we get

$$i' \cong \frac{3}{4} k \epsilon' A^2 \beta^2 \frac{1}{\lambda \left(2\lambda + \dfrac{r\Delta\lambda}{2} \right)} \tag{10}$$

In all of these cases i, (and i^1), is to be regarded as the intensity near the center (of the width) of the spectrum, and the range $\lambda_1 - \lambda_2$, in the case of continuous spectra, must be no larger than is consistent with approximate uniformity of the spectral intensity between these limits.

Comparing $\begin{cases} (3) \text{ and } (6) \\ (1) \text{ and } (8) \end{cases}$ and $\begin{cases} (4) \text{ and } (7) \\ (2) \text{ and } (10) \end{cases}$ we see that under the conditions which are most favorable to the compound spectroscope the intensity of the spectrum produced by the latter is not more than two-thirds in the case of continuous spectra,

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*The longitudinal aberration is proportional to $\frac{\kappa}{\beta^2}$ (Rayleigh, *Phil. Mag.*, Nov. 1879), and the resulting broadening of the image is therefore proportional to $\frac{\kappa}{\beta^2}\beta$, or $\frac{\kappa}{\beta}$, as above.

and less than one-third in the case of bright-line spectra, of the
intensity of a spectrum produced by an objective spectroscope
of the same resolving power and angular aperture.

Under practical conditions the advantage of the latter instru-
ment is even more marked, because ϵ is always less than ϵ',
generally not more than three-fourths to one-half as large. In
general, therefore, we may say that for a moderate[1] theoretical
resolving power and given telescope, the intensity of the spec-
trum formed by the objective spectroscope is about twice as
great in the case of continuous spectra and from four to five
times as great in the case of bright line spectra, as with the
compound spectroscope having an observing telescope of the
same angular aperture as that of the main telescope.

This gain in intensity, although important in itself, is greatly
accentuated by a corresponding gain in the purity of the spec-
trum.   This is a point which, strangely enough, seems to have
been overlooked.   It is easy to show that the objective spectro-
scope is in fact the only form in which the purity of the spectrum,
under the most favorable conditions, may be equal to the full
theoretical resolving power of the spectroscope train.   For we
have for the expression for purity

$$P = \cfrac{\lambda}{s\psi + \lambda \cfrac{\lambda\left(\frac{r}{R}\right)}{2s\psi + \lambda\left(\frac{r}{R}\right)} \; \lambda\left(\frac{r}{R}\right)} \; r \qquad (11)$$

where r is the theoretical resolving power of the instrument as
ordinarily defined, and R the theoretical resolution for lines of
width $\Delta\lambda$. But in the case of the objective spectroscope

$$s\psi = \omega A.$$

For stars the term ωA may be neglected in comparison
with λ. (It can hardly be more than $\dfrac{1}{10}\lambda$ even in the case of
the largest telescope now in use.)

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[1] For very large resolving powers the advantage is less marked in bright line
spectra because of the greater importance (*i. e.*, larger coefficient) of the term $r\Delta\lambda$ in
the case of the objective spectroscope.

Hence, if there is no appreciable aberration

$$P = R$$

or the purity is equal to the maximum theoretical resolution.

If we assume corresponding conditions in the case of the compound spectroscope, the diffraction pattern at the focal plane of the observing telescope will be

$$I = \int_{-\frac{\sigma}{2}}^{+\frac{\sigma}{2}} \frac{\sin^2 \phi}{\phi^2} \cdot \frac{\sin^2 \frac{\pi}{a_0}(\gamma - \phi)}{\left[\frac{\pi}{a_0}(\gamma - \phi)\right]^2} \, d\phi = \psi(\gamma, a) .$$

If the width of the slit is equal to the diameter of the first diffraction ring of the star image, $\sigma = 2\pi$. Under these conditions the value of I, for the part of the curve with which we are most concerned in determining resolution, is practically the same as that given by the integral

$$\int_{-\infty}^{+\infty} 2^{-\frac{\phi^2}{w^2}} \frac{\sin^2 \frac{\pi}{a_0}(\gamma - \phi)}{\left[\frac{\pi}{a_0}(\gamma - \phi)\right]^2} \, d\phi = \psi(\gamma, w\,a),$$

where the effective angular width w of the source is equal to σ. This last integral has already been investigated, and it has been shown that the diffraction curve which it represents is of such a form that resolution of a double source of which the two components were equal would occur when the angular distance between the centers of the geometrical images is

$$\Omega = \frac{4}{7} w + \frac{a^2}{w + a} . \tag{12}$$

In this case, that of a slit symmetrically illuminated by the central diffraction image of a star,

$$w = \frac{2\lambda}{a}, \text{ and since } a = \frac{\lambda}{a},$$

then

$$p_s = \frac{\lambda}{\frac{8}{7}\lambda + \frac{1}{3}\lambda} r = \frac{2}{3} r, \qquad \left(\frac{21}{31} r\right)$$

or the maximum purity (for absolutely monochromatic radiations) attainable with the compound spectroscope with the above width of slit is only two-thirds the maximum purity obtainable with the same resolving power in the objective spectroscope. It may be easily proved that the latter has a similar advantage in the case of non-monochromatic radiations.

If, then, we compare the intensities of the spectra produced by the two forms of instrument on the basis of constant *purity*, we see that in the case of continuous spectra the objective spectroscope is not twice but more than three times as efficient as the compound form, since in order to obtain the same purity of spectra with the latter the resolving power must be increased 50 per cent. and the intensity correspondingly decreased, both by the increased linear dispersion and the increased losses by reflection and absorption. With bright line spectra the same increase of resolving power is necessary (for constant purity), but the diminution in the intensity is less, because of the less effect of the increase in the terms containing r.

In case the image is broadened by aberration caused by atmospheric disturbances, the distribution of intensity in the star image will probably not differ greatly from the "law of errors" curve already assumed as representing the distribution in intensity in a spectral line of width $\Delta \lambda$. Hence, if we replace w by $\dfrac{\kappa}{A}$ in the expression for Ω (12) we get

$$p'_s = \frac{\lambda}{\dfrac{4}{7}\kappa + \dfrac{\lambda}{\kappa + \lambda}\lambda}\, r \; .$$

For a value of κ such as we have already considered in the calculation of intensities, (8) and (10), *i. e.*, $\kappa = 2\lambda$, we have

$$p'_s = \frac{2}{3}\, r = p_s .$$

For the corresponding case of the compound spectroscope (actual slit opening same as before) we have

$$p''_s = \frac{\lambda}{2\lambda + \dfrac{1}{5}\lambda}\, r = 0.45\, r$$

and $$\frac{p''_s}{p'_s} \cong \frac{2}{3} \text{ as before.}$$

If we double the aberration and open the slit of the compound spectroscope until the same quantity of light passes as before, we will practically halve the purity for both forms of instrument. We therefore come to the practical conclusion that the objective spectroscope has the same advantages over the compound form in the way of brightness and purity of spectra under bad conditions as it has under good conditions of work. But it must not be forgotten that with the slit spectroscope we can always attain any given degree of purity (less than the theoretical resolving power) by closing the slit and sacrificing the brightness of the spectrum. In the case of the objective spectroscope, however, the degree of purity attained at any time depends entirely on the value of κ, that is on the conditions of "seeing." For this reason the latter instrument does not possess the same advantages for photographic as it does for visual work. For in visual work there are occasional moments of good definition and of these the eye makes the most. Since the conditions of observation are frequently good enough to permit of nearly the limiting theoretical resolution of the telescope objective being reached in double star work, it would seem that we might hope to attain under these same conditions the full theoretical resolution of the objective spectroscope, and thus resolve and observe lines in stellar spectra (and possibly measure their position), which we can never hope to see with the compound spectroscope (such, for example, as the components of D_3). This advantage does not seem to have been as yet appreciated or at least utilized.

For photographic work the conclusions already drawn hold, provided the angular aperture of the telescope is sufficiently small to enable the full visual resolving power to be photographically attained. In order to do this the focal length must be from thirty-five to forty times the aperture (see THE ASTROPHYSICAL JOURNAL, May 1896, pp. 345–6). For large refracting telescopes it would be almost impossible to attain this ratio, but in

reflectors it could be easily done by using the Cassegrainian form
It is important to notice that the effect of aberration on the
resolving power varies only as the first power of β, and is there
fore independent of the focal length. The main difficulty in
photographic work is, that since the final record is the result of
an integration in time, so to speak, the variation in the size and the
mean position of "aberration disk" of the star on bad nights will
be very prejudicial to the purity of the photographic record.
But the magnificent results obtained by Pickering in photograph-
ing the spectra of a Aurigae, a Bootis, a Canis Minoris and many
other stars with an objective prism of only eleven inches aper-
ture, show how much we may reasonably hope to achieve with
objective spectroscopes of apertures equal to those used in con-
nection with our best compound spectrographs, provided only
that efficient prisms or gratings of the necessary size can be
constructed. In this case the larger the aperture the better the
results likely to be attained spectrographically, because of the
shortening of the time of exposure and the greater possibility of
utilizing the brief intervals of good definition.

METHODS OF DETERMINING MOTION IN THE LINE OF SIGHT WITH THE OBJECTIVE SPECTROSCOPE.

The principal objects for which the objective spectroscope is
likely to be used and for which its advantages over the com-
pound spectroscope would be most manifest, are : (1) Spectro-
graphic surveys for the purpose of determining spectral types of
stars and for singling out interesting objects for more detailed
examination. (2) Spectroscopic or spectrographic studies of
particular lines or groups of lines in the spectra of certain stars,
with reference either to their character or their identification.
(3) Measurements of velocities in the line of sight. (4) Accur-
ate measurements of absolute wave-lengths for the purpose of
determining shifting of the lines by the effect of pressure, etc.

The first of these objects is the only one for which the instru-
ment has been extensively used, and the success which it has
achieved in this line of work is too well known to require further

comment. The great advantages of the objective spectroscope for observations—particularly visual observations—of the second kind have been pointed out in the preceding paragraph. For the last two purposes, both of which involve accurate measurements of absolute or relative wave-lengths, the instrument has scarcely been used at all, although its application to (3) has frequently been suggested. We give below the various methods of measuring relative and absolute wave-lengths with the objective spectroscope which have been proposed by others, together with certain suggestions and experiments of our own.

TELLURIC LINES.

In Dunér's important researches on the rotation of the Sun, telluric lines were used as the standards of reference, and differential measures of the displacement of certain metallic lines were made at opposite ends of a solar diameter. The high precision of these measures would lead one to suppose that no reference marks better than telluric lines could be found for determinations of stellar motions in the line of sight, whether with the slit spectroscope or the objective prism. The B band and other telluric groups are visible in the spectra of many stars,[1] but in their position at the lower end of the spectrum the stronger lines do not offer very good marks for the micrometer; it is probable, however, that certain telluric lines could be advantageously used for the purposes of visual measurement. Were it not for the insensitiveness of photographic plates to orange and red light, there would be no difficulty in photographing the stronger lines with a good spectrograph, and under the very best conditions some of the finer lines, which could be more accurately measured, might be obtained. With commercial isochromatic plates, water-vapor lines such as those at λ 5886.193, λ 5887.445, λ 5919.860 and especially λ 5901.682 on Rowland's map might perhaps be photographed with the best spectrographs. It must be admitted that under existing conditions it is hardly probable that any of these lines could be photographed with an

[1] W. W. CAMPBELL, *Ap. J.*, **2**, 163, 1895.

objective spectroscope, unless it have some such resolving power as the Draper eleven-inch telescope with four objective prisms at the Harvard Observatory. Professor Pickering has searched for telluric lines in his large collection of photographs of stellar spectra, but hitherto without success.[1] It is to be hoped that photographic plates which are sensitive in the lower spectrum will ultimately be obtainable, as they cannot fail to be of great value for work of this kind.

ABSORBING MEDIA IN THE TELESCOPE.

It might be supposed that artificial lines could be produced in the objective spectroscope, by the absorption of media placed in the telescope tube, between the objective and the eye or the photographic plate. The only experiments which to our knowledge have been made in this direction are those of Professor Edward C. Pickering, carried on at the Harvard Observatory.[2] Didymium salts gave lines that were too diffuse, hyponitric fumes were unsatisfactory and of all the substances examined, not one produced lines which were sufficiently well-defined to permit of accurate measurement. While it is doubtful whether absorption spectra thus produced would give satisfactory results, it is perhaps worth while to make further experiments with various absorbing media. Only those could be successfully used which in comparatively small thicknesses give narrow and sharply defined lines, and but little general absorption.

MISCELLANEOUS METHODS.

In *A. N.* 3289 M. Artémie Orbinskij gives a method of measuring stellar motions in the line of sight by the aid of an objective prism. The spectra of two stars are photographed side by side on the same plate, and the displacements $d\lambda_1$ and $d\lambda_2$ of two lines at the extremities of one spectrum with reference to the corresponding lines in the other spectrum are carefully measured. The velocity of one star with respect to the other is then given by

[1] *Harvard College Observatory Annals*, **26**, Part I, p. xx.
[2] *Ibid.*

$$v = V \frac{d\lambda_1 - d\lambda_2}{n_1\lambda_1 - n_2\lambda_2},$$

where V is the velocity of light, and n_1, n_2 are the number of revolutions of the micrometer corresponding to a tenth-meter for the wave-lengths λ_1, λ_2 respectively. In making the photographs the objective prism is supposed to be in its ordinary position with the refracting edge parallel to the diurnal motion of the stars. It is evident that any relative displacement of the spectra in declination will materially affect the result. As the telescope must be set in different positions in order to bring on to the plate the star to be investigated and a second star of known velocity, difficulties due to flexure, variations in the temperature of the prism, and the gradual change of refraction during the exposures (tending to make the lines cross the spectrum obliquely) would probably be encountered. M. Orbinskij suggests methods of overcoming the first two of these difficulties, and others will be mentioned in the course of this paper.

In a note published in this JOURNAL,[1] Professor E. B. Frost describes a method similar to that of M. Orbinskij, which he devised in 1893. Instead, however, of bringing two stars side by side upon the same plate, Professor Frost proposes to measure the perpendicular distance between corresponding lines in the spectra of a star whose velocity is known and any other star on the plate whose velocity is desired, corrections being applied to reduce the measures to the center of the field. He is not prepared to say that the errors due to the distortion by the lens and prism will be less than those due to flexure in pointing at different stars in M. Orbinskij's method, nor does he consider that the plan proposed could compete with the spectrographic method. The chief value of Professor Frost's suggestion seems to us to be, as he himself points out, the possibility it affords of determining "the direction and order of velocity of a great number of stars, and thus to sift out large velocities and interesting cases" on just such photographs as those in Professor Pickering's extensive collections.

[1] *Ap. J.*, **2**, 235, 1895.

It should be added that the essential principle of the methods of M. Orbinskij and Professor Frost was recognized by Professor Pickering in 1891, as the following words indicate[1] : " The change in length of the spectrum due to the motion of the star would only amount to about one-sixth of the total motion, and could not readily be distinguished from a variation in temperature of the prism."[2] Mr. Maunder has recently stated that the same idea occurred to him in 1875.[3]

In the course of his investigations Professor Pickering made a number of experiments with auxiliary prisms, with the purpose of forming an image of the star itself upon some portion of the spectrum, to serve as a basis of measurement. The dispersion and deviation of the objective prism were neutralized by a small prism, and an achromatic prism having the same deviation as the objective prism was then inserted. As well-defined images could not be obtained in this way on account of the secondary · spectrum, trial was made of a doubly reflecting prism like a Fresnel rhomb, consisting of two right-angled prisms placed face to face, one of them having the necessary inclination. The color of the objective prism was not completely corrected however, and the auxiliary prism was then tried near one edge of the objective, the large prism having been moved to give it space. In this position the secondary spectrum of the lens gave a winged image of the star, a difficulty which was not overcome by further experiments.[4] If a hole were cut through the objective prism, and the reflecting prism placed at the center of the objective, it is probable that good results would be obtained. The form of double reflection prism shown in Fig. 1a, which has only three optical surfaces, would also be preferable to the Fresnel rhomb, on the score of both compactness and cheapness.

In the February 1896, number of the *Observatory* Mr. Maun-

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[1] " Preparation and Discussion of the Draper Catalogue," *Annals Harvard College Observatory*, **26**, Part I., p. xxi, 1891.

[2] It is perhaps worth mentioning that the differential displacement of the lines might be greatly increased by using the prism out of the position of minimum deviation.

[3] *O's'y*, **19**, 84, 1896.   [4] *Ibid.*

der describes certain methods of using the objective prism for measuring stellar motions which occurred to him several years ago. In the first of these a second telescope is attached to the tube of the principal telescope at such an angle as to point directly to the star, the photographic plate being placed at the point of intersection of the two optical axes. The star's trail is thus photographed upon the spectrum, and serves as a reference mark. In the second plan the refractive angle for different parts of the stellar spectrum is measured on the declination circle of the equatorial The third method requires the use of an objective prism smaller in aperture than the objective, so that stars whose positions are known may be photographed on the same plate with the spectra. The value of these methods would depend upon the possibility of eliminating the effect of flexure in the first two cases, and of correcting for atmospheric refraction in the third.

M. Deslandres has recently proposed that by means of a slit and collimator placed in front of the objective prism, a metallic spectrum be photographed on the same plate with that of the star; a second star spectrum and a second metallic spectrum are then photographed on the same plate. The displacement of corresponding lines in the stellar spectra less that of the same lines in the comparison spectra give the relative velocities of the two stars. The function of the comparison spectra is to eliminate errors due to changes in temperature of the prism and flexure in the telescope tube. Since it is essential to accurate measurement that the angle between the star and the axis of the telescope be exactly the same during each exposure, a finder is attached at a fixed angle to the telescope tube, and the observer keeps the star on the cross-hairs by means of the slow motions. Errors in guiding are determined by measurement of the star image photographed at the focus of a third telescope attached to the finder. This is essentially Fraunhofer's original form of apparatus, with the micrometer replaced by a photographic plate, and the addition of a third telescope and an arrangement for producing comparison spectra. It is not easy

to see any important advantages of this device for determining stellar motions. As compared with the spectrograph, the gain in shortness of exposure due to the use of the objective prism would probably be offset by the loss in accuracy resulting from the relative flexure of the various parts of the apparatus. Moreover, as Professor Keeler has already pointed out in a review of the method,[1] the resolving power of the instrument as used for the production of comparison spectra would of necessity be very small, even if a prism of large angle were employed. For this reason, the comparison lines would be poorly defined, and consequently not well suited to accurate measurement.

The idea of using a comparison spectrum with the objective prism is not an entirely new one. Several years ago Professor Pickering determined the scale of his objective prism photographs by a process analogous to, but not identical with, the one suggested by M. Deslandres. The 11-inch Draper telescope, with its battery of four objective prisms, was placed in such a position that the parallel rays of sunlight coming from a slit at the focus of a horizontal 15-inch reflecting telescope, entered its objective, and formed a solar spectrum in the center of the photographic plate.[2] The full aperture of the prisms was utilized in this way, but it is evident that serious errors might arise from the difference in temperature of the prisms and the flexure of the telescope. Several methods of using a comparison spectrum also suggested themselves to one of the present writers two years ago, but no description of them was published.

In all of the methods hitherto described a comparison spectrum in which is utilized the full resolving power of the prism, is needed to determine the effect of variations in the temperature of the prism and in the flexure of the telescope. Such a comparison spectrum can be obtained if the objective spectroscope is used as a Littrow spectroscope (Fig. 1). Light from the spark at E enters the slit at S and falls upon the right-angled prism P,[3] from which it is reflected through the objective and the

[1] *Ap. J.,* **3,** 311, 1896.
[2] *Annals Harvard College Observatory,* **26,** Part I., p. xvi., 1891.
[3] Placed on one side of the axis of the telescope.

objective prism. If the prism is so inclined that the light of the spark falls normally upon its outer face, some of this light will be reflected back to form the spectrum of the spark upon a photographic plate at the focus of the telescope. The dispersion in this case would be twice that of the stellar spectra formed by the
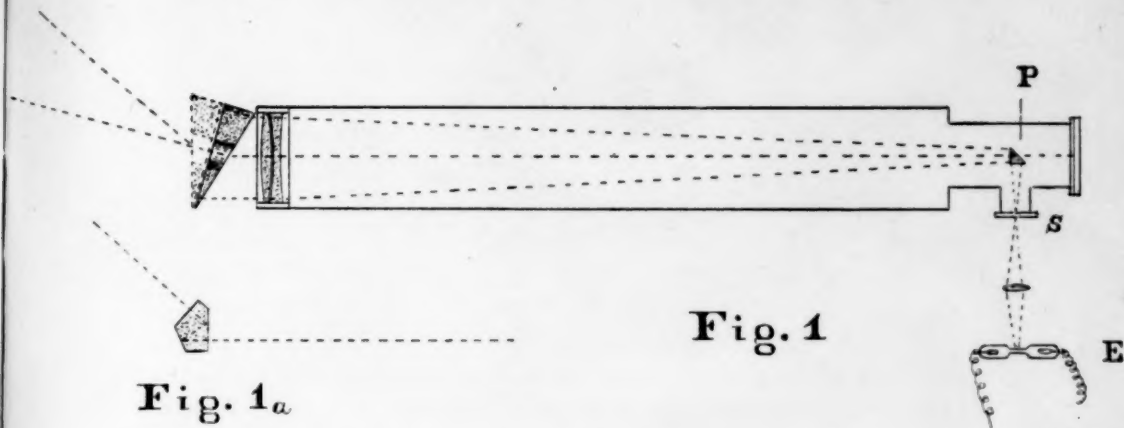
Fig. 1

Fig. 1$_a$

same prism, but this would be an advantage in detecting displacements due to changes of temperature, etc. If, however, it were desired to have the dispersion the same as that of the stellar spectra, the objective prism could be made of two prisms of equal angle separated by a narrow air space, as indicated in the figure. The light from the spark would then be reflected back at the second surface of the lower prism. In this case the compound prism could be used at the position of minimum deviation for the star, while in the first plan proposed the departure of the prism from minimum deviation would increase with its refracting angle. On account of the comparatively small amount of light reflected back from the prism, the exposure on the spark spectrum might be continued during the whole time of the exposure on the star, a very decided advantage. If the light is too feeble, the reflecting surface could be very lightly silvered, but except in the case of the very brightest stars this would probably be unnecessary. We believe that a combination of this method

for producing comparison spectra with either the double reflec-
tion prisms of Fig. 1*a* placed at the center of the objective or
with the methods of measurement of Professor Frost or M.
Orbinskij, would be likely to yield valuable results.

For the sake of completeness it may be added that Zöllner's
reversion prism device might be used with the objective spectro-
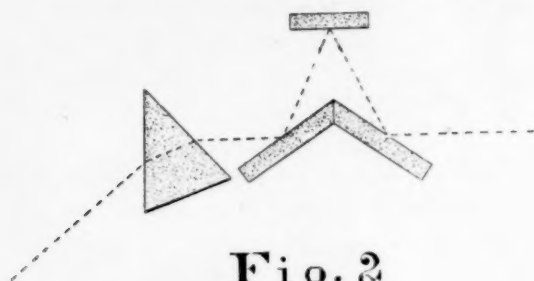
Fig. 2

scope for the determination of motion in the line of sight in
four ways: (1) After photographing the spectrum of the star
and spark (using the comparison method suggested above), the
objective prism is rotated through 180°, the telescope again set
upon the star, and the process repeated. The perpendicular
distance between two lines in the comparison spectra, minus that
between the corresponding star lines, gives the displacement
required. It is evident that corrections would be needed for
errors in pointing the telescope and following the star. (2) In
order to reduce the errors due to flexure, a direct-vision objec-
tive prism might be used, rendering unnecessary the second
pointing of the telescope. So far as we know, the only direct-
vision objective prism hitherto employed proved to be unsatis-
factory on account of its great absorption.[1] Except for small
apertures, the direct-vision prism-mirror combination, first sug-
gested by Fuess and reinvented by one of the present writers,[2]
would also be impracticable on account of the size of the optical
flat required. (3) After the star and comparison photographs

[1] KONKOLY, *Handbuch für Spectroskopiker*, p. 258.
[2] *Phil. Mag.*, October 1894.

have been taken as in (1), a reversion attachment formed of three plane surfaces (Fig. 2) is placed between the prism and the objective, and a second set of exposures made. (4) Or this reversion attachment may be made to cover one-half the objective, so that the direct and reversion photographs can be made simultaneously, the reversion device being so constructed that the reversed stellar spectra fall slightly above or below the direct ones, and not upon them. This reversion arrangement, although much cheaper than a large reversion prism, would likewise be impracticable for large apertures for the same reason as in (2).

Another method upon which some experiments have been made, and which will answer well under some conditions for making absolute measurements in prismatic spectra, is an interference one similar in principle to that first employed by Rubens,[1] and more recently by Rubens and Snow,[2] in the measurement of wave-lengths in the infra-red spectrum. In Rubens' apparatus the two parallel glass plates which were used to produce interference bands were placed outside the slit of the spectrometer. In the case of the objective prism this arrangement is obviously impossible, and the two plates must be placed just in front of or just behind the prism. The interference phenomena produced by the double reflection from the two contiguous surfaces of the plates are the same in either case, and consist, as is well known, of a series of dark bands crossing the spectrum at points whose wave-length is determined by the relation

$$\lambda = \frac{2d\cos i}{m} = \frac{K}{m},$$

where d is the perpendicular distance between the two plates, i the angle of incidence of the light, and m a number depending on the order of the interference. The two quantities K and m on the right hand side may be determined by experiment by using the instrument to form a solar spectrum, and measuring

[1] *Wied. Ann.*, **45**, 238, 1892.

[2] *Wied. Ann.*, **46**, 529, 1892; *A. and A.*, **12**, 231, 1893.

the position of two bands of order *m* and *m*+*a* with reference to two Fraunhofer lines of known wave-length, λ_1 and λ_2. These two quantities once determined, the wave-length of a line in any spectrum may be found by comparing its position with that of a band of known order.

Fig. 3

It is to be observed that in this method of determining absolute wave-lengths a change in the index of refraction of the prism by reason of a change in temperature, or a change in deviation caused by a shifting of its position, is without effect on the result. All that is necessary is that the distance *d*, and the angle *i*, shall remain constant.

The first may be best secured by making one plate slightly larger than the other and clamping both in a rigid metal frame of a cross section shown in Fig. 3, the distance between the two plates being adjusted by means of screws *a, a'*. To secure the maximum quantity of light, the back reflecting surface should be full silvered and the front one "half silvered." These two plates are placed in front of the prism, and make a fixed angle with it and the axis of the telescope, being most conveniently placed so as to give the direct vision combination previously referred to.

In the preliminary experiments with this arrangement no difficulty was experienced in setting on the center of the inter-ference fringe with sufficient accuracy, even though the latter was several times broader than the spectrum lines. Indeed, as

is well known, the accuracy of setting on a line or fringe increases until the width becomes at least ten to twenty times the width of the cross-wires. The principal difficulty is that when a line falls near a minimum it is rendered so faint as to be very difficult to set upon. The great practical difficulty is the same as before, *i.e.*, the necessity for using two large optical flats, one of which would require in this case to be a plane parallel piece. With very large apertures the use of such a combination would of course be out of the question.

THE OBJECTIVE GRATING.

The most direct and convenient method of determining both relative and absolute wave-lengths with the objective spectro-scope is, as with all others, by the use of a grating in place of a prism train. The use of the objective grating in place of the objective prism was first suggested, we believe, by Jewell,[1] who proposed an ingenious method of making a transmission grating by photography. It was recently pointed out that this plan would be impracticable in the case of large telescopes, because the plate on which the grating is photographed would have to be an optical flat, which would be more expensive than one of the lenses of the objective itself.[2] If this method of making a grat-ing were adopted, it would be better and more practical to either photograph it directly upon the front face of the objective, devoting the telescope exclusively to spectroscopic work for the time being, or to have an extra front lens (which would be somewhat less expensive than an optical flat of the same size and quality), and photograph or *rule* the grating permanently upon it. Another plan suggested[3] by one of the writers was to make an objective grating by Fraunhofer's original method. A trial grating of this kind has since been constructed in our workshop by Mr. William Gaertner for the 12-inch refractor of the Kenwood Observatory. Two screws 27^{cm} long with about 63 threads to the centimeter were carefully cut in brass, on a Rivett precision lathe. For

[1] *A. and A.*, **13**, 44, January 1894.
[2] *Ap. J.*, **3**, pp. 61–62, 1896.   [3] *Ibid.*

the purpose of making the preliminary experiments described below it was considered sufficient to finish the screws in the lathe, without grinding.   They were then cut in two along their axes, and the half screws mounted parallel to each other on the opposite sides of rectangular frames 33^{cm} by $36^{cm}.5$, made of brass bars of $2^{cm}.5$ square section.   The two frames were next clamped together and mounted on centers, and No. 40 B. & S. copper wire
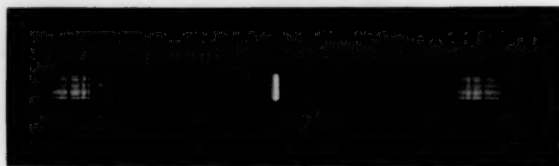
FIG. 4.

at constant tension was wound across the screws in the successive threads, as Fraunhofer made his first gratings.   After the winding had been completed the wires were soldered to the screws, and the frames separated, leaving two transmission gratings with perfectly opaque lines and transparent spaces.   The brass frames were each provided with four clamping-screws, by means of which they could be easily fastened to the cell of the 12-inch photographic objective.

Sirius was selected as the first star to be photographed, and early in March several exposures were made on its spectrum with fairly successful results.   After the focus had been determined a large number of stellar spectra were photographed during March and April.[1]   One of these is reproduced in Fig. 4.[2] In examining this photograph it should be remembered that the grating is a very coarse one, the total number of wires being only about 1700.   As the ratio of aperture to focal length in the telescope is $\frac{1}{18}$, it is evident that the photographic resolving power could hardly be greater than about 800, even

[1] Many of these photographs, including those referred to in the text, were made by Mr. S. B. Barrett, Fellow in Astrophysics in The University of Chicago.

[2] In order to bring out the lines clearly, it was necessary to strengthen them somewhat on the glass positive from which the cut was made.   The second order spectra are easily obtained with somewhat longer exposure.

under theoretically perfect conditions. On many nights the grating wires were set into vibration by the wind, and in most cases the seeing was not very good in the early evening, when the exposures were made. It is therefore not probable that the effective resolving power exceeded 400 to 500, or that of a dense flint prism of about 5^{mm} base.

The absolute wave-lengths of the lines in stellar spectra photographed with the objective prism are determined from the ordinary equation of the transmission grating

$$\lambda = \frac{s}{m} \sin \left(\frac{\delta_1 + \delta_2}{2}\right),*$$

where δ_1, δ_2 are the angular distances of corresponding lines from the central image, s the grating interval and m the order of spectrum. The scale of the photographs is easily determined by measuring the linear separation of stars whose positions are known. In a series of measures of the lines $H\gamma$, $H\delta$, $H\epsilon$, and $H\zeta$ in the first order spectra of 54 Leonis we have obtained the wave-lengths 4339.4, 4101.1, 3970.6, 3890.6, Rowland's values (neglecting the last two places of decimals) being 4340.7, 4101.8, 3970.3, 3889.1 respectively. The mean error of measurement in this case was about 1 tenth-meter or about $\frac{1}{12}$ the practical resolving power of the telescope. There should be no difficulty in constructing objective gratings in the manner described with at least twice as many lines to the centimeter, and with apertures as great as a meter. In order to prevent the wires from vibrating in the wind they may be soldered to light rods running across the frame parallel to the screws. With such a grating the accuracy of measurement ought to be increased at least twenty-five times, making it possible to determine velocities in the line of sight with an accuracy approaching that attainable with a slit spectroscope.

The exposure must of course be considerably longer with objective gratings than with objective prisms and they can, there-

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*A slight correction is necessary if the incident light is not perpendicular to the plane of the grating, *i. e.*, if the central star image is not in the optical axis of the telescope or if the grating is not perpendicular to the latter.

fore, hardly be expected to compete with prisms except for certain purposes. The facility with which wave-lengths can be measured in the photographed grating spectra is a strong point in their favor. The cost of the gratings is also comparatively small, the one used in our experiments not exceeding one-thirtieth that of an equally large objective prism of small angle. This last advantage becomes of course more and more marked as the aperture increases. For example, the objective grating which it is proposed to make for the Yerkes telescope should cost less than one-half of 1 per cent. as much as an objective prism of the same resolving power and aperture.

KENWOOD OBSERVATORY,
May 20, 1896.

MINOR CONTRIBUTIONS AND NOTES.

ON MR. JEWELL'S OBSERVATIONS OF THE SPECTRUM OF MARS.

MR. LEWIS E. JEWELL again contends, in the April number of this JOURNAL, that all the spectroscopic observations of Mars thus far made were totally inadequate for detecting water-vapor in that planet's atmosphere. I am disposed to accept his conclusion, but not his reasoning.

The *reason* which Mr. Jewell assigns for his belief is that the resolving-powers of the spectroscopes employed were entirely too low to show the individual vapor "lines." Is his reasoning correct? In my opinion it is wrong. The nature of the observations seems to be unfamiliar. May I quote a paragraph from my paper on "The Spectrum of Mars"?[1] "Now while all these lines can be observed *individually* in the solar spectrum, owing to the high dispersion which can be used, they can only be observed as groups or bands in the Martian and lunar spectra, on account of the faintness of those spectra and the low dispersion which must be employed." On the page of my paper immediately following the above quotation, Mr. Jewell can find eight or ten other passages to the same effect. I did not claim to see the individual "lines" (introduced by our atmosphere), but only the "bands" or "groups" of lines collectively. The question of resolving-power has so little to do with the problem that we may safely neglect it.

Mr. Jewell's contention that the evidences of vapor absorption could not be, and therefore were not, seen is practically equivalent to saying that a large diffuse nebula or star cluster cannot be seen at all unless the telescope be powerful enough to resolve it into stars. The fact is, the experienced observer would really select a telescope of rather low resolving-power as being the more efficient,—just as the experienced observer would select a spectroscope of rather low dispersion for observing the vapor bands in a planet's spectrum. How-

[1] *Pub. A. S. P.*, **6**, 233.

ever, he would put a large telescope in front of the spectroscope, rather than the opera-glass that has been suggested as a substitute.

One sentence as to the meteorological question brought up : a summer month on Mt. Hamilton would convince Mr. Jewell that his explanation of why there are fogs in our valleys is very insufficient.

W. W. CAMPBELL.

April 16, 1896.

CARL NICOLAUS ADALBERT KRUEGER.[1]

WE regret to record the death of Professor Dr. A. Krueger, Director of the Royal Observatory of the University of Kiel, and editor of the *Astronomische Nachrichten.*

Carl Nicolaus Adalbert Krueger was born in Marienburg, West Prussia, on December 3, 1832. After attending the Gymnasium of Elbing and later that of Wittenberg, he entered the University of Berlin in 1851, with the intention of studying astronomy. In the following year, however, he took up practical work as a voluntary assistant in the Observatory at Bonn, where he was appointed second assistant in 1853. Almost simultaneously with Krueger's appearance at the Bonn Observatory, the great work of the "Bonner Durchmusterung" was initiated by Argelander. With Schönfeld as his fellow observer, Krueger entered upon his part of this important undertaking with characteristic energy. Between 1852 and the beginning of 1859 he observed with the comet-seeker 810 zones out of a total of 1841 in the northern sky. Of the 476 revision zones observed between 1854 and 1861 he is to be credited with 304.

In spite of the great demands made upon his time by the work of observation and computation involved in the preparation of the Durchmusterung, Krueger found opportunity to pursue investigations in other fields. In 1853 he undertook the study of the motions of the minor planet Themis, whose perturbations by Jupiter enabled him to determine the mass of the latter planet. He also carried on observations of variable stars. In 1858 the heliometer previously used by Winnecke came into his hands, and was most successfully employed in a series of parallax determinations. Four years later he was appointed Professor of Astronomy and Director of the Observatory in Helsing-

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[1] For many of the facts embodied in this note we are indebted to an appreciative notice of Krueger's life and work, by Professor Dr. A. Auwers, in *A. N.* 3349.

fors, where he remained fourteen years, engaged in various theoretical and practical investigations. At the time of his appointment he married the eldest daughter of Argelander. The most important work of Krueger during his stay in Helsingfors, and later during the four years of his directorate at the Gotha Observatory, was the observation and reduction of 14680 star places in the zone 55° to 65° of the great catalogue of the Astronomische Gesellschaft.

The death of Peters in 1880 left the *Astronomische Nachrichten* without an editor. The exacting demands of this position made the choice of his successor a matter of grave concern, and the Astronomische Gesellschaft paid a fitting tribute to Krueger's worth by placing the editorial supervision of the foremost journal of astronomy in his hands. His work as editor began in 1881, shortly after his acceptance of the Professorship of Astronomy in the University of Kiel. The forty volumes which have appeared under Krueger's direction remain to testify to his editorial ability. The improvements effected by him will stimulate his successor to further efforts, and here, as in other fields, the influence of his life will long be felt.

THE TOTAL ECLIPSE OF THE SUN, APRIL 16, 1893.

REPORT AND DISCUSSION OF THE OBSERVATIONS RELATING TO SOLAR PHYSICS.[1]

THE memoir first gives reports by Mr. Fowler and Mr. Shackleton as to the circumstances under which photographs of the spectra of the eclipsed Sun were taken with prismatic cameras in West Africa and Brazil respectively on April 16, 1893. These are followed by a detailed description of the phenomena recorded, and a discussion of the method employed in dealing with the photographs. The coronal spectrum and the question of its possible variation, and the wave-lengths of the lines recorded in the spectra of the chromosphere and prominences, are next studied.

Finally, the loci of absorption in the Sun's atmosphere are considered.

The inquiry into the chemical origins of the chromospheric and prominence lines is reserved for a subsequent memoir.

The general conclusions which have been arrived at are as follows:

[1] Abstract of a paper read before the Royal Society.

(1) With the prismatic camera, photographs may be obtained with short exposures, so that the phenomena can be recorded at short intervals during the eclipse.

(2) The most intense images of the prominences are produced by the H and K radiations of calcium. Those depicted by the rays of hydrogen and helium are less intense, and do not reach to so great a height.

(3) The forms of the prominences photographed in monochromatic light (H and K), during the eclipse of 1893 do not differ sensibly from those photographed at the same time with the coronagraph.

(4) The undoubted spectrum of the corona in 1893 consisted of eight rings, including that due to 1474 K. The evidence that these belong to the corona is absolutely conclusive. It is probable that they are only represented by feeble lines in the Fraunhofer spectrum, if present at all.

(5) All the coronal rings recorded were most intense in the brightest coronal regions, near the Sun's equator, as depicted by the coronagraph.

(6) The strongest coronal line, 1474 K, is not represented in the spectrum of the chromosphere and prominences, while H and K do not appear in the spectrum of the corona, although they are the most intense radiations in the prominences.

(7) A comparison of the results with those obtained in previous eclipses confirms the idea that 1474 K is brighter at the maximum than at the minimum Sun-spot period.

(8) Hydrogen rings were not photographed in the coronal spectrum of 1893.

(9) D_3 was absent from the coronal spectrum of 1893, and reasons are given which suggest that its recorded appearance in 1882 was simply a photographic effect due to the unequal sensitiveness of the isochromatic plate employed.

(10) There is distinct evidence of periodic changes of the continuous spectrum of the corona.

(11) Many lines hitherto unrecorded in the chromosphere and prominences were photographed by the prismatic cameras.

(12) The preliminary investigation of the chemical origins of the chromosphere and prominence lines enables us to state generally that the chief lines are due to calcium, hydrogen, helium, strontium, iron, magnesium, manganese, barium, chromium and aluminium. None

of the lines appear to be due to nickel, cobalt, cadmium, tin, zinc, silicon or carbon.

(13) The spectra of the chromosphere and prominences become more complex as the photosphere is approached.

(14) In passing from the chromosphere to the prominences, some lines become relatively brighter but others dimmer. The same line sometimes behaves differently in this respect in different prominences.

(15) The prominences must be fed from the outer parts of the solar atmosphere, since their spectra show lines which are absent from the spectrum of the chromosphere.

(16) The absence of the Fraunhofer lines from the integrated spectra of the solar surroundings and uneclipsed photosphere shortly after totality need not necessarily imply the existence of a reversing layer.

(17) The spectrum of the base of the Sun's atmosphere, as recorded by the prismatic camera, contains only a small number of lines as compared with the Fraunhofer spectrum. Some of the strongest bright lines in the spectrum of the chromosphere are not represented by dark lines in the Fraunhofer spectrum, and some of the most intense Fraunhofer lines were not seen bright in the spectrum of the chromosphere. The so-called "reversing layer" is therefore incompetent to produce the Fraunhofer spectrum by its absorption.

(18) Some of the Fraunhofer lines are produced by absorption taking place in the chromosphere, while others are produced by absorption at higher levels.

(19) The eclipse work strengthens the view that chemical substances are dissociated at solar temperatures.

J. NORMAN LOCKYER.

A NEW FIRM OF INSTRUMENT MAKERS.

WE take pleasure in calling attention to the establishment in Chicago of a new firm of instrument makers. Messrs. Kandler & Gaertner, the members of the firm, have had wide experience in the design and construction of instruments of research. Mr. Kandler was employed for many years in the workshops of Starke & Kamerer in Vienna; previous to his connection with the Kenwood Observatory he was known in Chicago as the junior member of the firm of Seelig

& Kandler, manufacturers of surveying instruments. Mr. Gaertner is a graduate of the Fachschul für Mechaniker in Berlin, an institution established by the Gesellschaft für Optik und Mechanik for the purpose of training instrument makers. He has been connected with several European and American workshops of the first class, including those of A. Repsold & Sons, Hamburg, the United States Coast and Geodetic Survey and the Smithsonian Astrophysical Observatory, Washington, and A. Hilger, London. During the past few months both members of the new firm have been engaged in the workshop of the Kenwood Observatory in constructing various special instruments for astronomical and astrophysical research. Having had this opportunity to become familiar with their work, we gladly recommend Messrs. Kandler & Gaertner to those who desire to have instruments constructed or repaired. On account of the difficulty of getting bolometers made elsewhere, it is worth while to mention that Mr. Gaertner is very skilful in constructing them.

RECENT PUBLICATIONS.

A LIST of the titles of recent publications on astrophysical and allied subjects will be printed in each number of THE ASTROPHYSICAL JOURNAL. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors.

For convenience of reference, the titles are classified in thirteen sections.

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